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Design, Evaluation, and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements

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[2] Some divisions within the center are located at Boulder, CO 80303.

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NBS technical note

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FOREWORD

The research described in this report represents the culmination of over 3 years of work at the National Bureau of Standards (NBS), Electromagnetic Fields Division, Boulder, Colorado, to carefully evaluate, develop (when necessary), describe, and document the methodology for performing radiated susceptibility/vulnerability (EMS/V) measurements using a reverberation chamber. This effort was jointly funded by the Naval Surface Weapons Center (NSWC), Dahlgren, Virginia; Rome Air Development Center (RADC), Griffiss Air Force Base, Rome, New York; and the NBS. Three major tasks were outlined. These were to:

1. Determine how well a shielded enclosure could be made to operate as a reverberation chamber to establish time averaged (statistically determined), randomly polarized, uniform EM fields as a function of spatial position, frequency and chamber quality factor (Q);

2. Evaluate interaction effects between the chamber and equipment under test (EUT) placed inside the chamber to determine:
   a. The range of applications of the measurement techniques (i.e., where the technique could or should not be used),
   b. Whether measurement results obtained using the reverberation chamber could be correlated with results obtained using anechoic chambers or open field sites, and
   c. To identify pertinent chamber calibration parameters;

3. Develop a technique applications and use manual.

These tasks were addressed sequentially in three major phases. The first phase was to design, construct, assemble and evaluate an empty (without the presence of an EUT inside) reverberation chamber with associated instrumentation and software to evaluate its electrical performance characteristics. This phase of the work began in January 1982 and was completed by the end of 1983. Results of this effort are contained in Section 2 of this report. Section 2 discusses the modification of a 2.74 m x 3.05 m x 4.57 m welded steel shielded enclosure located at NBS into a reverberation chamber. Information given includes theoretical concepts, physical design and construction details, and the evaluation of the empty chamber's electrical parameters. These parameters are excitation and reference receiving antennas voltage standing wave ratio (VSWR), loss, Q factor, wave impedance, spatial E-field distribution versus frequency, and determination of the test field level.

The second phase of the work was to evaluate the interaction effects between the chamber and the EUT placed in the chamber. This effort occupied the latter part of 1983 through 1984. The results are contained in Section 3 of this report. The third phase was to develop methodology and evaluate the use of the reverberation chamber for susceptibility measurements and compare the results to other more conventional measurements techniques such as anechoic chambers and to other reverberation chambers. This study included the selection and susceptibility evaluation of four samples of EUTs: a one centimeter dipole probe, a ridged horn antenna, a series of rectangular TEM transmission cells with apertures and a modified 7.0 cm (2.75") diameter folded fin aircraft rocket (FFAR). The first three "reference standard" EUT's were selected because they could be characterized theoretically. The fourth EUT (FFAR) was more typical of an operational EUT which is more indicative of the actual type of equipment routinely tested for EM susceptibility. Results were obtained for this phase of the effort during 1984 and 1985. Details of how the measurements were performed, including setups, approaches, and instrumentation and software requirements are contained in Section 4. The final task was to document these results, presented in Section 5, and to produce a reverberation measurement technique applications and use manual. This, of course, is one of the purposes of this report. Section 6 gives a brief summary and conclusions drawn from this study. Some of the more significant are: 1) the NBS chamber lower useful frequency limit is 200 MHz; 2) the spatial variation in the statistically determined E-field established in the chamber is approximately ± 8 dB at 200 MHz and decreases to ± 2 dB at 2 GHz; 3) the preferred measurement approaches are mode tuned (explained in section 4.3.2) at frequencies below 2 GHz and mode stirred (also explained in section 4.3.2) at frequencies above 2 GHz; 4) the loading effect, of lowering the chamber's Q by inserting the EUT, should be limited to an increase in chamber loss ≦ 6 dB or a minimum tuner effectiveness ≧ 20 dB; 5) the average wave impedance in the chamber is approximately 120π; 6) the maximum E-field is approximately 7-8 dB greater than the average E-field established in the chamber; 7) scattering from EUT does not significantly influence the E-field statistical, spatial distribution; 8) the directional characteristics of antenna or EUT placed inside the chamber are effectively lost; 9) the response of EUT measured inside a reverberation chamber is less than when measured inside an anechoic chamber (open space) in proportion to the EUT open space gain; 10) the response of EUT to an interference field after it has penetrated the EUT's shield appears to be equivalent in both reverberation and anechoic chambers; and 11) the experimental error analysis suggests that Root Square Sum (RSS) errors in establishing the test field inside a reverberation chamber range from approximately ± 10 dB at 200 MHz to ± 4 dB at 18 GHz.

Section 7 provides suggestions for future research and Section 8 acknowledges the significant contribution of others to this project. References cited are given in Section 9.

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This report presents the results of work at the National Bureau of Standards, Boulder, Colorado, to carefully evaluate, document, develop (when necessary), and describe the methodology for performing radiated susceptibility/vulnerability measurements using a reverberation chamber. The report describes the reverberation chamber theory of operation, construction, evaluation, functional operation, and use for performing immunity measurements. It includes an estimate of measurement uncertainties derived empirically from test results and from comparisons with anechoic chamber measurements. Finally, it discusses the limitations and advantages of the measurement technique to assist potential users in determining the applicability for this technique to their electromagnetic compatibility (EMC) measurement needs.

Key Words: electromagnetic susceptibility/vulnerability; estimated uncertainty; evaluation; measurement procedures; reverberation chamber

1. Background and Introduction

The use of mode tuned or stirred reverberation chambers for performing EMC measurements is a relatively new method which appears to have considerable potential for electromagnetic susceptibility/vulnerability testing [1-7]. The idea of reverberating a shielded enclosure as a way to improve the EMC measurement results obtained using the enclosure was first proposed in 1968 [1]. Since then measurement procedures have been developed for implementing the technique for both radiated susceptibility and emission testing, but with considerable skepticism and a general lack of acceptance on the part of many EMC engineers. Reasons given include: 1) a lack of information about interaction effects between the EUT, reverberation chamber, and sources used to excite the chamber, 2) significant unanswered questions concerning the interpretation and accuracy of the measurement results, and 3) the lack of clear correlation of test results with other more conventional measurement techniques. Emphases for performing the work described in this report result from numerous advantages suggested for use of a reverberation chamber. These include:

1. Electrical isolation from or to the external environment;
2. Accessibility (indoor test facility);
3. The ability to generate high level fields efficiently over large test volumes;
4. Broad frequency coverage;
5. Cost effectiveness;
6. Potential use for both radiated susceptibility and emission testing with minor instrumentation changes; and
7. No requirement of physical rotations of the equipment under test (EUT).

These advantages are somewhat offset by limitations which include loss of polarization and directivity information relative to the EMC/EMI profile of the EUT and reduced measurement accuracy. However, this technique does offers a time efficient, cost effective way to evaluate EMC performance of large equipment using existing shielded enclosures with only minor modifications. The concept utilizes the shielded, high-Q, multimoded environment to obtain uniform (time averaged) fields that may simulate "real world", near field environments.

This report describes efforts to answer some of the questions referred to above and outlines an approach using this technique for EMS/V testing. It also describes efforts to identify a "correlation factor" between reverberation chamber and anechoic chamber obtained results, and outlines a detailed, step by step procedure for performing EMS/V tests. An experimental error analysis is given to provide insight into the magnitude of the measurement uncertainties expected for tests performed using this method.

2. Development of an Operational Reverberation Chamber

2.1 Theoretical Concepts

A reverberation chamber is a large (in terms of wavelength) high quality (Q) cavity whose boundary conditions are continuously and randomly perturbed by means of a rotating conductive tuner or stirrer. The time averaged field inside such a cavity, when a sufficient number of modes are excited, is formed by uniformly distributed plane waves coming from all directions. This property causes the polarization of the field to vary randomly hence eliminating the need, or the utility of physical rotation of test objects in the field. This has its obvious advantages and disadvantages as is apparent from the results and conclusions given in this report.

Two analytical approaches can be used to provide basic knowledge for designing a reverberation chamber. One involves the direct solution of Maxwell's equations with time varying boundary conditions. A formal solution using this direct approach is rather difficult to obtain. In the second approach, suitable linear combinations of basic eigenmodes of the unperturbed cavity (without mode stirrer or tuner) with time-dependent expansion coefficients are taken to represent the field and to satisfy approximately the boundary condition on the surface of the rotating mode stirrer or tuner [8]. The main advantage of this latter approach is that the unperturbed eigenfrequencies and eigenmodes are much easier to calculate, and the problem can be reduced to a more familiar one under special conditions. A necessary condition for the validity of this method is, however, that the total number of eigenmodes which can exist inside a chamber be large for a specified frequency and chamber size. Thus, the measurement technique using reverberating chambers is good for high frequency application. Typical frequencies of operation are from a few hundred MHz to 18 GHz and above.

The frequencies at which particular modes can exist inside a shielded, rectangular enclosure of dimensions a, b, and d are given as [9]

$$f_{mnp} = 150 \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2} \quad \text{(MHz)} \tag{1}$$

where m, n, and p are integers.

Figure 2.1 gives the distinct frequencies of resonances of the first few modes for the NBS reverberation chamber. There are 26 resonant modes at distinct frequencies below 150 MHz and 63 resonant modes at distinct frequencies below 200 MHz.

As expected, the total possible number of eigenmodes, N(f), inside an unperturbed, lossless, rectangular chamber increases in steps with frequency. A smooth approximation to N(f) has been given by [8,10,11]:

$$N_s(f) = \frac{8\pi}{3} abd \left\{\frac{f}{c}\right\}^3 - (a + b + d) \frac{f}{c} + \frac{1}{2}, \tag{2}$$

where abd in m^3 represents the chamber volume, f is the operating frequency in Hz, and c is the speed of wave propagation in the chamber medium (usually air) in m/s. Note that the first term in (2) is identical to the well-known Weyl's formula derived originally for the same problem by a different approach, and is proportional to the chamber volume and the third power of frequency. The second term is the edge term, which is proportional to the sum of the linear dimensions of the chamber. This term may by used to modify Weyl's result, especially in the lower frequency range. Also, the inner surface area of the chamber, 2(ab + bd + da), is not involved in (2). An example is given in figure 2.2 showing N(f) as curve 1, $N_s(f)$ as curve 2, and Weyl's formula as curve 3 for the NBS chamber. Note that none of the dimensions of the NBS chamber (2.74 m x 3.05 m x 4.57 m) are equal. Equivalent examples for a square-based chamber (2.17 m x 4.19 m x 4.19 m) and a cubic chamber $(3.37\ m)^3$, both of which have the same volume as that of the NBS chamber, are shown respectively in figures 2.3 and 2.4 for comparison purposes. Clearly, wider steps for curve 1 in figures 2.3 and 2.4 as compared with figure 2.2 are observed. This is true even though the smooth approximation $N_s(f)$ remains almost identical for all the three chambers. The main reason for this is due to the increased mode degeneracy for the last two chambers, under which the total number of distinct eigenmodes with respect to a given operating frequency and chamber size decreases.

While the total number of eigenmodes inside an unperturbed chamber is an important design criterion, another equally important factor to consider is the mode density function, dN/df, which represents the change in number of modes in a given frequency interval. Ideally, the chamber should be designed, if possible, so that the distribution of the modes is uniform. To determine the exact shape of dN/df involves using impulse functions since they are the derivatives of step functions. It is not difficult to see that within a given frequency interval, the average distance between the different impulses for the NBS chamber is shorter than that for the other two chambers having the same volume. An alternative quantity to examine for exhibiting this property is

$$\Delta N = \int_{\Delta F} \frac{dN}{df}\, df \quad , \tag{3}$$

which represents the increase or decrease in mode number within a frequency interval of Δf.

Results of ΔN when Δf = 1 MHz are presented respectively in figures 2.5 through 2.7 for the NBS chamber, the square-based chamber, and the cubic chamber. The uniformity of mode distribution in the frequency interval of 1 MHz is better for the NBS chamber (figure 2.7). This is the reason that the NBS chamber was designed with unequal dimensions. As a consequence, more uniformity for the electromagnetic field is expected within the NBS chamber than for chambers that have two equal sides or that are cubic, with the same volume and frequency of operation. Or, the NBS chamber should be capable of being operated with an extended lower frequency limit than other chambers of the same volume, in order to meet a given degree of uniformity for the final, expected field distribution. Thus, one of the general design criteria for a reverberating chamber is to make the volume as large as possible and the ratio of squares of linear dimensions as nonrational as possible.

A third design criterion, namely, the quality or Q factor, must also be considered in designing a reverberation chamber. Since there are so many eigenmodes which may exist in an unperturbed chamber with each mode carrying its own Q value [8,10,11], it is not always trivial to define a quality factor for the chamber as a whole. A composite quality factor for an unloaded chamber (without an EUT in it) within a specified frequency range can be obtained approximately from the equation [8],

$$\tilde{Q} = \frac{3}{2}\,\frac{V}{S\delta_s}\,\frac{1}{1 + \frac{3\lambda}{16}\left(\frac{1}{a} + \frac{1}{b} + \frac{1}{d}\right)} \tag{4}$$

where V is the chamber's volume in cubic meters, S is the internal surface area in square meters, and $\delta_s = \sqrt{\frac{2}{\omega\mu\sigma}}$ is the skin depth in meters, λ is the wavelength in meters, and a, b, and d, are the chamber's internal dimensions in meters.

The physical meaning of (4) may be interpreted by comparing it with the individual Q values of all the modes in the form of a cumulative distribution. Since $V/(S\delta_s)$ is a common factor whether the composite quality factor defined above or the quality factor for individual modes is considered, it is more convenient to present the results in terms of 1/Q values normalized with respect to $S\,\delta_s/V$. Thus, the variable used herein is

$$\alpha = \frac{1}{Q}\,(V/S\,\delta_s)\ . \tag{5}$$

Examples of the cumulative distribution of α for the NBS chamber are given respectively in figures 2.8 - 2.10 for three different frequency bands. For the frequency band of 180 to 200 MHz in figure 2.8, the total number of modes existing in this band of 20 MHz is 69, with each mode having its own Q-value. The probability of having a high upper-bound value of $\alpha \leqq$ 0.80 (or a lower-bound for Q) is almost 100%, and that for a low value of $\alpha \leqq$ 0.48 (or a high value for Q) is only about 10%. This implies that almost all of the 69 modes in this frequency band have $\alpha \leqq$ 0.80. The arithmetic mean of 0.623 and the standard deviation of 0.090 are also indicated in the figure. The probability of having $\alpha \leqq$ 0.623 (arithmetic mean) is 50%, meaning that at least one half of the 69 modes have $\alpha \leqq$ 0.623.

For the case presented in figure 2.9, where the frequency band is from 330 to 350 MHz, also of a bandwidth of 20 MHz, there are 261 modes, an increase in number of modes relative to that in figure 2.8. This is because of higher frequency. A similar interpretation of the α values (or Q values) carried by these modes in terms of probability applies. There are now a small number of modes (low probability) carrying a value of α as low as 0.43 (high Q). The arithmetic mean and standard deviation are, respectively 0.630 (higher than the corresponding value in figure 2.8) and 0.085 (lower than the corresponding value of figure 2.8). A higher value of arithmetic mean implies that one half or more of the 261 modes carry a higher value of α (lower Q) compared to the frequency band considered in figure 2.8. A decrease in standard deviation reveals that a greater number of modes have α-values closer to the arithmetic mean.

If we consider a still higher frequency band 480 to 500 MHz such as that illustrated in figure 2.10, 534 possible modes will exist in the same bandwidth of 20 MHz. The arithmetic mean increases further to 0.646 while the standard deviation decreases further to 0.074, indicating that a greater number of modes will have still higher α values near the arithmetic mean. This tendency, increasing in arithmetic mean and decreasing in standard deviation with increased frequency, yields a limiting mean of $\alpha \leqq 0.667$ with a 50% probability, which also agrees precisely with the limiting value for composite $\tilde{\alpha}$ derived from (4) and (5).

Thus, even though there are a large number of possible modes existing in a specified operating frequency band for a reverberating chamber, with each mode carrying its own value of α or Q, the probability that $\alpha \leqq 0.667$ (or $Q \leqq 1.5\ V/S\sigma_s$) is 50%. This implies that one half of the modes have α-values less than 0.667. Preliminary estimation of a quality factor to characterize the reverberating chamber as a whole, based on the simple expression of $\tilde{Q}$ in (4), for the purpose of predicting the field strength level to be generated in the test zone is indeed very useful.

Finite Q values also imply that more than 1 mode can be excited at a single frequency. The extent to which modes not specifically resonant at a given frequency are excited is, of course, dependant upon the particular modes' Q, and how close the modes' resonant frequencies are to the given frequency.

The composite $\tilde{Q}$ estimated from (4) is considered an upper-bound value because it does not take into account losses other than that due to wall conductivity. In reality, some loss will also occur due to leakage from the chamber, loss in antenna support structures, etc., and loss in the chamber's wall coatings. Hence an alternative means of determining chamber Q can be achieved from measuring the chamber's loss. Chamber loss is determined experimentally by measuring the difference between the net input power, P_t, delivered to the chamber's transmitting antenna, and the power available, P_r, at the reference antenna terminals. A photograph showing the interior of the NBS reverberation chamber is shown in figure 2.11. If the energy is uniformly distributed over the volume of the chamber, an empirical value (Q') can be obtained [6] using the equation,

$$Q' \approx 16\,\pi^2 \frac{V}{\lambda^3}\,\frac{P_r}{P_t}\quad , \tag{6}$$

where V and λ are as previously defined.

Typical losses for the NBS chamber are shown in figure 2.12. The two curves show the average and minimum loss as a function of frequency. These results were determined statistically by rotating the chamber's tuner through 200 increments of 1.8 degrees and measuring the chamber's loss at each position for all test frequencies. The smooth curves are an estimated curve fit for the data.

Results obtained using (4) to calculate the composite $\tilde{Q}$ and by using the data shown in figure 2.12 and (6) to calculate the experimental Q' are shown in figure 2.13. Figure 2.13a gives the curves for the calculated values of $\tilde{Q}$ and Q' and figure 2.13b shows the ratio of $\tilde{Q}$ to Q'. At frequencies above approximately 1 GHz the ratio approaches a constant value approximately equal to 3 or a loss equivalent of approximately 5 dB.

The Q factor of the chamber, of course, influences the rf input power requirements to generate the EM field levels inside the chamber for performing susceptibility tests. The average power received by the reference antenna, $\bar{P}_r$ in watts, is related to the average power density, $\bar{P}_d$ in watts per square meter, of the EM field inside the chamber by the equation,

$$\bar{P}_d = \bar{P}_r/\bar{A}_r \ (\text{W/m})^2 , \tag{7}$$

where $\bar{A}_r$ is the average effective aperture in square meters of the receiving antenna.

If the receiving antenna is subjected to EM energy coming from all aspect angles and random polarizations, the average gain of the antenna over 4π solid angle is unity. (i.e., The field distribution at each point in the antenna aperture plane is assumed to be a composite of randomly polarized plane waves. This implies that the orientation of the receiving antenna will not influence the measured response and hence the effective gain of the antenna is unity.) The effective aperture of the antenna then is given as, $\bar{A}_r = \lambda^2/8\pi$ [12]. However, data obtained, as shown later in this report, indicates that these conditions are not achieved ideally (the field is not completely randomly polarized and incident at all aspect angles and the assumption that the average gain for the antenna is one is not exact). Hence, a more practical value to use for the effective aperture appears to be $\lambda^2/4\pi$. This value has been suggested previously for use in reverberation chambers for determining the "equivalent" average power density, $\bar{P}_d$ [4]. Equation (7) then becomes,

$$\bar{P}_d' \approx \frac{4\pi \bar{P}_r}{\lambda^2} \quad (\text{W/m}^2) . \tag{8}$$

Combining (6) and (8), we can obtain an expression for comparing the average, equivalent power density inside chambers of different size, assuming equal net input power, or

$$\frac{\bar{P}'_{d_1}}{\bar{P}'_{d_2}} \approx \frac{V_2}{V_1} \frac{Q_1'}{Q_2'} = \frac{S_2}{S_1} \frac{\delta_2}{\delta_1} , \tag{9}$$

where the subscripts 1 and 2 refer to the two different enclosures, #1 and #2. For example, assume the #1 enclosure is the NBS enclosure with $S_1 = 69.63 \ \text{m}^2$ and the #2 enclosure is a larger chamber constructed of the same metal ($\delta_1 = \delta_2$) with dimensions, 3.51 m x 5.18 m x 10.82 m, or $S_2 = 224.42 \ \text{m}^2$; this would give a ratio in average power densities (assuming the same net input power) of $\bar{P}'_{d_1}/\bar{P}'_{d_2} = 3.22$ (i.e., the average power density inside the larger enclosure would be approximately 1/3.22 or 0.311 times as much as that in the NBS enclosure). Note that the validity of (9) is dependent upon a number of assumptions alluded to in its derivation.

2.2 Physical Design Considerations

A number of criteria should be considered in physically designing a reverberation chamber EM susceptibility/vulnerability measurement system. They can be addressed under the following categories:

1. Chamber physical shape and volume,
2. Chamber quality factor (Q),
3. Chamber auxiliary needs (venting, electrical power, EUT visual monitoring, EUT operational and functional monitoring requirements),
4. Tuner/stirrer(s) design, and
5. Chamber excitation and field monitoring.

2.2.1 Chamber Physical Shape and Volume

This criterion was addressed in Section 2.1. For optimum chamber performance (i.e., spatial field uniformity and accuracy in determining the test field level), especially at the low end of the frequency intended for use, the volume of the chamber should be as large as possible and the ratio of the squares of the chamber's linear dimensions should be as nonrational as possible. Choice of chamber size would be dictated by test volume size requirements, lowest test frequency, and budget considerations.

2.2.2 Chamber Quality Factor, (Q)

The second criterion, that of chamber Q, is established by carefully considering trade-off options. If one has the option of designing and constructing a new shielded chamber, it is advantageous to use solid welded aluminum or copper construction since this will result in a higher Q than if sheet steel is used. Presumably one can always lower the Q of the chamber, if desired, by inserting material such as lossy wall coatings or a limited amount of rf anechoic material. The reason for lowering the chamber Q is to increase the bandwidth of the chamber's modes, thus improving mode overlap and smoothing the EM field uniformity vs. frequency response characteristics, especially at the lower test frequencies. Doing this, however, increases the rf input power needed to generate the required field strengths and reduces the effectiveness of the chamber's tuner to redistribute energy uniformly into modes in all three axes of the chamber. In addition, the time required for the chamber test field to arrive at its steady state condition, after the input power to the chamber is applied, is a function of chamber Q. The higher the Q the longer the settling or charging time. This could have significant implications if the reverberation chamber is to be used for pulsed rf susceptibility testing. Regardless of the metal used in the chamber's construction (aluminum, copper or steel) it should be standard practice to keep the chamber clear of lossy material such as wood or absorbing materials except for special purposes.

2.2.3 Chamber Auxiliary Needs

The third criterion, chamber auxiliary needs, must be established based upon the intended use and the upper test frequency for use. Venting panels should use screens with apertures significantly smaller than waveguide below cutoff at the maximum intended test frequency. Electrical power supplied to outlets inside the chamber, EUT visual monitoring, and EUT operational and functional monitoring requirements are similar to conventional shielded enclosure requirements. A bulkhead panel similar to that shown for the NBS reverberation chamber in figure 2.14 can be used to access the excitation and reference receiving antennas, and the EUT. Care must be taken to ensure that the shielding integrity of the enclosure is not compromised by access holes or cables, etc. This may require the use of high resistance (carbon impregnated) lines [13] or fiber optic links for monitoring the EUT. In addition, waveguides below cutoff access ports can be very useful.

2.2.4 Tuner Design

The fourth criterion is to design the tuner to ensure its effectiveness to redistribute the energy inside the enclosure and hence to tune the field. To achieve this, the tuner must be electrically large ($>\lambda/2$ at the lowest frequency of operation) and be shaped or oriented to distribute energy into all possible modes. Three such tuners are shown in figures 2.15a, 2.15b, and 2.15c. The first tuner (figure 2.15a) was developed by McDonnell Douglas Corp. [2,14,15] after extensive testing to optimize the design for use in their translational electromagnetic environment chamber (TEMEC) facility. The second tuner (figure 2.15b) is used by the Naval Surface Weapons Center in their reverberation chamber [16]. The third tuner (figure 2.15c) is used in the NBS reverberation chamber. The tuner is mounted as shown in figure 2.16, with the blades bent at an angle of approximately 45 degrees to the ceiling to improve its scattering of the field evenly in all directions. The tuner mounting includes a shielded housing with internal metal wipers to prevent rf leakage from the chamber via the tuner shaft to the stepping motor. Details of the housing and motor mounting arrangement are shown in figure 2.17. The tuner controller system which includes the stepping motor and a computer accessed controller, allows movement of the tuner in increments as small as 0.113 degrees (3200 steps per revolution) at rates from seconds up to hours per revolution. The motion was optimized for as smooth a motion of the tuner as possible.

A test to determine how effectively the tuner is functioning is to measure the ratio of the maximum to minimum received power of the receiving antenna as a function of tuner position. This is done while maintaining a constant net input power to the enclosure's transmitting antenna. The results of such measurements made with the NBS tuner are shown in figures 2.18a and 2.18b. The magnitude of the ratio is dependent upon a number of factors including tuner shape, size, orientation, and the Q of the enclosure. The average value of the maximum to minimum ratio is higher in the empty chamber. (Data for figure 2.18b were obtained with 4 pieces of 66 cm x 61 cm x 61 cm rf absorber placed in the center of the chamber 0.5 meter above the floor). The purpose for inserting the absorber was to simulate a gross loading effect of an EUT placed in the enclosure. A lower loss (ratio) is indicative of a higher Q and more effective mode tuning. This influences the spatial uniformity of the test field (statistically) as is shown in section 2.3. A reasonable guideline for proper operation of the tuner is a minimum tuning ratio of 20 dB.

Multiple tuners have been used in some reverberation chambers [3,6]. Typically they are mounted on opposite walls to improve the stirring of the fields in the chamber. This is especially important if the tuners are flat, thus acting as scatterers in only one plane. The tuner controller system used in the NBS system allows for control of several tuners simultaneously. This may be particularly advantageous if the reverberation chamber is especially large or is compartmentalized (multiple sections). Examples of compartmentalized chambers are a large chamber divided into two sections by a separating wall or a small chamber placed inside a large chamber. Both arrangements have been proposed for using the reverberation chamber method for measuring shielding effectiveness of materials and enclosures [17].

2.2.5 Chamber Excitation and Field Monitoring

The fifth consideration in designing a reverberation chamber EMC measurement system is in the selection and mounting of appropriate antennas for exciting and monitoring the EM fields inside the chamber. The following parameters are used in selecting the antennas:

a) frequency range of interest,
b) input power rating (>200 watts),
c) bandwidth (>10:1 if possible),
d) minimum VSWR (low as possible),
e) efficiency for exciting modes inside chamber,
f) minimum size, and
g) durability.

The typical frequency range of application is from 200 MHz to 18 GHz or higher. A number of candidate antennas could be used in this range. No single antenna has sufficient bandwidth to cover the full range with the possible exception of the long wire antenna. Based upon the above and, to a certain extent, the antennas available at the Electromagnetic Fields Division of NBS, the following were selected for evaluation.

a) Long wire antenna (200 MHz - 18 GHz),
b) Log periodic antenna (200 MHz - 2 GHz),
c) Monopole antenna (200 MHz - 1 GHz),
d) Bow-tie antenna (200 MHz - 1 GHz),
e) Leaky 50 ohm coaxial cable (200 MHz - 1 GHz),
f) Ridged horn (1.0 GHz - 12 GHz),
g) Double ridged circular horn (2.0 GHz - 18 GHz).

The efficiency with which energy can be injected into or coupled out of the chamber via transmitting or receiving antennas is determined by: 1) the voltage standing wave ratio (VSWR) of the antennas (i.e., the impedance match between the rf source and the transmitting antenna or between the receiving antenna and its output detector), and 2) the ability of the antennas to couple energy into or out of the particular modes that exist at the test frequencies of interest. Rotating the tuner changes the chamber's boundary conditions and hence, shifts the mode excitation frequencies. This, of course, changes the characteristics of the field inside the enclosure which in turn influences the effective VSWR of the antennas. The Q factor of the enclosure as a resonant cavity also has considerable effect upon the VSWR of the antenna. This is particularly true at frequencies below a few GHz.

The placement and orientation of the transmitting and receiving antennas can also influence the operation of the chamber [18]. Two positions or orientations are recommended: 1) position the transmitting and receiving antennas in different corners of the chamber, oriented toward the corners as shown in figure 2.19, or 2) position one of the antennas in a corner oriented toward the corner, for example the reference receiving antenna, with the other antenna (transmitting antenna) sufficiently far away and oriented toward the tuner. The first arrangement was selected for use in the NBS chamber. The purpose for these configurations is to couple energy into and out of all chamber modes as efficiently and uniformly as possible without significantly favoring particular modes or favoring a direct path coupled signal between the transmitting and receiving antennas.

Installation of a long wire antenna inside the chamber is different from other antennas because it uses the chamber wall as its ground plane to obtain as close to a 50 ohm impedance as possible. Details for designing the taper transition region of the long wire antenna are shown in figure 2.20. A photograph of the long wire antenna installed inside the NBS chamber is shown in figure 2.21. The long wire extends around two surfaces of the chamber. This is done to achieve, however somewhat limited, the purpose of the locations and orientation configurations referred to above for other conventional antennas.
G Based upon the results of data obtained for various antenna pairs selected from the above list, the following four antennas were chosen for use in the NBS chamber in the following frequency ranges:

1) Long wire (200 MHz - 1000 MHz), receiving mode,
2) Log Periodic (200 MHz - 1000 MHz), transmitting mode,
3) Ridged horn (1.0 GHz - 10 GHz), transmitting and receiving modes,
4) Double ridged circular horn (2.0 GHz - 18 GHz), transmitting and receiving modes.

Within the recommended frequency bands of operation, the long wire and log periodic antennas can accommodate up to 1000 watts input power, and the ridged horns and double ridged circular horns can accommodate up to 200 watts input power.

A number of preliminary tests were performed to determine the operational parameters of the NBS reverberation chamber using these antennas and to evaluate the interactions between EUT, the chamber, and the rf sources used in performing these measurements. Some of these tests and their results were previously published [19]. The VSWRs and coupling efficiency of these four antennas placed inside the empty NBS chamber are given in figures 2.22 and 2.23. Figure 2.22 shows the maximum, average, and minimum VSWR obtained statistically by measuring return loss from the antennas, operating in the transmitting mode, as a function of tuner position at discrete frequencies from 200 MHz to 18 GHz. The tuner was stepped at 1.8 degree increments (200 steps) through a complete revolution. Figure 2.22a is for the long wire antenna operating over the complete frequency range. Figure 2.22b, is the composite VSWR of three antennas (#2, #3, and #4) used within the frequency bands shown in the figure's caption. In the past a long wire antenna has been used quite extensively as a reference receiving antenna across the full frequency range [4,14,17,]. Its input VSWR is not as low, especially at frequencies above 1 GHz, as for the composite of the three antennas. Also, at frequencies above approximately 2 GHz, rotation of the tuner appears to have a minor influence on the VSWR of the antennas. This feature can have considerable impact upon the decision as to what approach to use in performing susceptibility measurements as discussed in section 4.1 of this report. Figure 2.23 shows the coupling efficiency or loss between the long wire antenna transmitting (200 MHz - 18 GHz), and a composite of the three antennas receiving. This figure is provided for comparison with figure 2.12. The long wire antenna is not as efficient in coupling energy into the chamber and hence, the loss is greater, particularly above 1 GHz.

The quality factor of the chamber as a resonant cavity also has considerable effect upon the VSWR and coupling efficiency of the antenna placed inside, especially at frequencies below a few GHz. This is shown in figures 2.22c and 2.24. These data were obtained with four pieces of 66 cm x 61 cm x 61 cm rf absorber placed in the center of the chamber's test zone. Note the significant reduction in the VSWR variations of the transmitting antenna associated with the substantially lower Q in the enclosure and the significant increase in the chamber loss.

2.3 Determination of Wave Impedance and E-Field Amplitude Distribution Inside Reverberation Chamber

2.3.1 Determining the Test Field and Wave Impedance Amplitudes

The field strength in the chamber can be determined in two ways. The first is to measure the power received by the reference antennas, and then determine the equivalent power density in the enclosure from (8). The equivalent electric field, $\bar{E}_a$, is then found using the expression,

$$\bar{E}_a = \sqrt{\bar{\eta}' \, \bar{P}_d} \approx \frac{4\pi}{\lambda} \sqrt{30 \, \bar{P}_r'} \quad (V/m), \tag{10}$$

where $\bar{\eta}'$ is the statistically averaged wave impedance in the chamber. This averaged wave impedance is assumed to be approximately equal to 120π ohms. Obviously, the wave impedance inside the reverberation chamber will have large variations as a function of tuner orientation and chamber location. To test the validity of (10), independent measurements were made of the maximum, average, and minimum magnetic and electric fields in the chamber. These measurements were made using a one centimeter diameter loop probe and a one-centimeter long dipole probe. The probes were rotated through three orthogonal orientations aligned with the chamber axes and located at the center of the test zone. The magnitudes of the total magnetic and electric fields were then determined as the square root of the sum of the squared values of each of the three components respectively for both the magnetic and electric fields. The corresponding ratios of the electric-field and magnetic-field amplitudes for a data base of 200 positions of the tuner were then used to determine an "equivalent" wave impedance. The results are shown in figure 2.25. Four curves are given. Three curves show the maximum, average and minimum wave impedance determined as a function of frequency. The fourth curve shows the wave impedance calculated from the ratio of E to H when the electric-field was a maximum. Even though the wave impedance varies widely as expected with frequency, the average wave impedance at frequencies above 200 MHz (the lower frequency limit recommended for this chamber) is approximately 120π ohms. This then, provides evidence that (10) is valid, at least for determining the average E-field in the chamber. The fourth curve was included because, as will be discussed later in this report, the convenient parameter for comparing reverberation chamber with anechoic chamber obtained EUT susceptibility data is the EUT's peak response. This typically corresponds to a maximum electric field in the reverberation chamber. Note that the wave impedance corresponding with the maximum E-field typically is greater than 120π ohms and was found to be as large as 1600 ohms thus contributing to an error as large as 6 dB in determining the maximum E-field if (10) is used.

The second method used to determine the field strength in the reverberation chamber is to measure the electric field using an electrically small dipole probe that has been previously calibrated in a standard uniform field. This is the same dipole probe, referred to above, that was used to determine the chamber's wave impedance. The assumption made in using the probe is that since it is electrically small, the fields measured in the reverberation chamber over the aperture of the dipole will be uniform (i.e., "equivalent" to the standard uniform field used in the probe's calibration); and hence the probe's response will give an accurate measurement of the "equivalent" field strength in the chamber. Results of the measurements comparing the electric-field strength generated in the chamber based upon these two methods are shown in figure 2.26. The maximum and average E-field strength data were normalized to one watt net input power. The agreement shown is typical of the random variations in the data used to determine the field in a reverberation chamber. The systematic offset difference between the field determined using the reference antenna and that determined using the probe is, however, less than 3 dB. This result also strengthens the validity of (10).

2.3.2 Maximum Versus Average Amplitude Responses

Another important observation from figure 2.26 is the approximate 7-8 dB difference in signal amplitude between the maximum and average field strengths. This can be explained simply in terms of the structure of the cavity modes in the chamber [20]. For a cavity of dimensions, a, b, and d, modes in all three dimensions can be represented as

$$\phi_{mnp}(x,y,z) \propto \sin\frac{m\pi x}{a} \sin\frac{n\pi y}{b} \sin\frac{p\pi z}{d} \, , \tag{11}$$

where x, y, and z correspond to the three orthogonal axes of the chamber and m, n, and p are the associated mode numbers.

An antenna typically responds to a specific field component, or in the reverberation chamber case, to the composite field impinging upon its aperture. However, measured power is related to ϕ^2_{mnp} x,y,z). The maximum value of ϕ^2_{mnp} (x,z,z) occurs when each component is a maximum or

$$\text{Max}\,(\phi^2_{mnp}(x,y,z)) \leq 1. \tag{12}$$

The average value of $\phi^2_{mnp}(x,y,z)$ is given by

$$\text{Ave}\,(\phi^2_{mnp}(x,y,z)) = \frac{1}{abd}\int_V \phi^2_{mnp}(x,y,z)\,dxdydz \approx \frac{1}{8}. \quad (13)$$

The ratio of Max $(\phi^2_{mnp}(x,y,z))$/Ave $(\phi^2_{mnp}(x,y,z))$ in the limit then is 8 which corresponds to 9 dB (i.e., this is the theoretical maximum difference that can exist between the maximum and average responses of an antenna or EUT measured in a reverberation chamber). In practice, the mode mixing is not 100 percent efficient to achieve a perfect average nor does one obtain a perfect maximum in all three dimensions. Hence the average difference of 7 to 8 dB shown in figure 2.26 is expected.

In the past, a question regarding the validity of maximum or "peak" reverberation chamber results has been raised. However, this question seems to be resolved as apparent by examining the relationship between maximum and average measurements in the reverberation chamber exhibited in figure 2.26 and from the implications of (12) and (13). These results suggest one can extract one set of data (e.g., average) from the other (e.g., maximum) quite accurately (within ± 2 dB), assuming of course, that the response of the EUT is linear.

2.4 Spatial E-Field Distribution

Tests were made to determine the uniformity of the maximum and average values of the E-field in the chamber as a function of spatial position and frequency. Seven NBS isotropic probes [21] designed to operate at frequencies up to 2 GHz were placed inside the enclosure as shown in figures 2.19 and 2.21. Each probe has three orthogonally oriented dipoles aligned with the enclosure axes. Measurements were made of the field strength of each orthogonal component at the seven locations for each tuner position (200 steps of 1.8 degree increments). The maximum and average values for each component and the corresponding amplitudes were then determined from the complete data set for a normalized net input power to the chamber of 1 watt. The results of these measurements are shown in figure 2.27. These measurements were made in 50 MHz increments from 100 MHz to 2.0 GHz. The spread of the data points show the spatial field variation inside the enclosure at the indicated frequencies. Note at 200-300 MHz the spread and potential errors in determining E-field amplitude is as great as ±8 dB, decreasing to approximately ±2 dB at 2.0 GHz. Note also the large difference in the three orthogonal components at frequencies below 150 MHz. This is especially apparent from inspecting figure 2.28 which shows the average values of the seven statistically determined average and maximum E-fields for each component and their composite total determined from figure 2.27. Strong mode structure is indicated in the chamber at frequencies below 150 MHz (i.e., the presence of a dominant mode with its associated directional properties). Hence, there are insufficient modes for proper operation at these frequencies. At frequencies above 150 MHz, the relative amplitudes of the field components are approximately the same and the composite total of the average E-field components is approximately 4.8 dB greater than the individual components. This indicates that the measured value of the average of each component is independent of polarization of the dipole. (i.e., $E_{x(ave)}$ is independent of $E_{y(ave)}$, etc.). Thus,

$$E_{t(ave)} = \sqrt{(E_{x(ave)})^2 + (E_{y(ave)})^2 + (E_{z(ave)})^2} \approx \sqrt{3}\,(E_{(x,y,\text{or } z)ave}).$$

The composite total however, of the E-field components' maxima (figure 2.28b) is less than 4.8 dB. This indicates that the maximum measured values for each component are not independent. (i.e., $E_{x(total)}$ is a function of $E_{y(total)}$, etc.). The implication is that if multiple receptors are involved in establishing the maximum susceptibility of an EUT (or for example in measuring the E-field in the chamber by using an isotropic probe with 3 orthogonal dipoles), the difference between the maximum and average response may be less than the typical 7 to 8 dB referred to in section 2.3.

2.5 Multiple Excitation of the Chamber

Electromagnetic fields were generated inside the chamber using two separate antennas simultaneously excited in the frequency ranges, (200-400) MHz, and (1000-2000) MHz. The antennas used for the frequency range (200-400) MHz were a log periodic and a long wire described previously. Two ridged horns were used in the frequency range (1.0-2.0) GHz. The spatial, statistical, E-field uniformity did not improve significantly over using a single antenna excitation in the 200-400 MHz frequency range; however, it did improve slightly (from approximately ± 2 dB to ± 1.5 dB variations) in the frequency range (1.0-2.0) GHz.

The E-field amplitude in the chamber decreased when using two excitation antennas, in both frequency ranges, assuming the same net input power as for a single antenna. The decrease was approximately 1 dB in the frequency range (200-400) MHz and approximately 1.5 dB in the frequency range (1.0-2.0) GHz. This loss however, can be accounted for in the losses in the additional rf transmission line cables and the second excitation antenna (i.e., the antennas are not 100% efficient in converting input rf power to radiated power).

3. Interaction Effects Between Chamber, Source and Reference Antennas, and EUT.

3.1 Placement Constraints of EUT

Constraints on the placement of EUT inside the reverberation chamber are a result of the proximity effect of the chamber walls on the test field and upon the EUT. Measurements were made of the E-field close to the chamber's walls for comparison with measurements made of the E-field within the test zone outlined by the matrix of seven probes shown in figure 2.21 Two locations were selected: 1) 0.5 m from the chamber's side and back wall, 1.0 m above the floor; and 2) 0.12 m from the side wall approximately mid-way between the chamber's ends and 0.5 m above the floor. Location 1 was selected so the EUT test zone would be clear of obstructions but also with the probe far enough from the chamber's walls, hopefully, to avoid significant proximity effects. Location 1 measurements were consistent with the measurements made at the 7 probe locations. Location 2 was selected to determine just how significant the proximity effect is at distances less than one third wavelength (<800 MHz). The average E-field measured at location 2 was approximately 2 dB lower at frequencies from 200 to 400 MHz than the E-field measured in the test zone. The field close to the chamber wall then increased as a function of frequency, approaching the test zone measured field strength at frequencies above 1 GHz. These results indicate a need to maintain a minimum spacing for the reference antenna, field measurement probe(s), and/or EUT of at least $\lambda/3$ from the chamber's walls at the lowest test frequency. This equates to approximately 1/2 meter at 200 MHz for the NBS chamber. An exception to this guideline may be a desired spacing between the EUT and the chamber floor or walls. This spacing may be dictated by the test plan. If the EUT is electrically large (many wavelengths) it may be necessary to have a separation distance from the chamber walls greater than $\lambda/3$ at frequencies where $\lambda/3$ is less than 1/2 meter or greater than 1/2 meter under some test conditions to prevent shadowing effects from influencing the spatial distribution of the test field. Results of scattering effects measurements discussed in section 3.2 suggest shadowing is not a signficant problem, if the EUT is placed in the center of the test zone as far from the walls as possible.

3.2 Scattering Effects of Metal Objects upon E-field Distribution

Two test objects were selected to simulate an EUT placed in the chamber to evaluate their scattering effect upon the field distribution inside the chamber. The first object was a solid welded aluminum box 30 cm x 50 cm x 60 cm in size. The second was an electronic equipment rack 56 cm x 67 cm x 114 cm in size. Tests were made to determine the E-field uniformity or distribution over the test zone matrix defined earlier using 6 isotropic probes (figure 2.19) with each of the two test objects placed at the center of the test zone. (The probe at the center of the test zone was removed to accommodate the test objects.) Figures 3.1a and 3.1b show the two test objects placed inside the enclosure. The mean value of the maximum and average values for each E-field component (vertical, longitudinal, and transverse) and their composite total were determined for each of the 6 probes. The results, shown in figure 3.2, give a comparison with the empty chamber E-field distribution measurements shown in figure 2.28. Little or no difference was noted in the statistical (average and maximum) values measured.

3.3 Loading Effects of EUT on Chamber

One of the concerns expressed about using a reverberation chamber for EMC measurements was the realization that if the EUT absorbed energy from the chamber (i.e., demonstrates susceptibility) it would reduce the Q of the chamber and thus affect the measurement results. Typically this is compensated for by simply increasing the net input power to the chamber transmitting antennas as required. This may not be sufficient if inserting the EUT lowers the chamber's Q to the extent that the chamber no longer reverberates or the tuner will no longer sufficiently stir the modes, (i.e., the chamber no longer functions properly). Recall that the absolute amplitude of the test field level inside the chamber is determined from the reference antenna received power measurements. The assumption is that this measurement is unaffected by the loading effect of the EUT. Two simple tests were used to evaluate the loading effect: the first was to insert a 500 MHz, half-wave, resonant dipole near the center of the chamber's test zone to determine if energy coupled from the chamber to the dipole would reduce the field strength in the chamber. This test was intended to simulate the loading effect of a simple resonant EUT. Field strength measurements were made again using the seven probe matrix and the long wire antenna as a reference receiving antenna to determine the level of the test field, before and after inserting the resonant dipole. A constant normalized input power of 1 watt was applied at the input of the chamber log periodic transmitting antenna to establish the field in the chamber. The following observations were made:

1) Energy is conserved (i.e., power coupled from the chamber via the dipole results in a proportional decrease in the E-field in the room).

2) The 500 MHz resonant dipole and the long wire receiving antenna coupled approximately the same amount of power from the room.

The seven probe matrix used to determine the spatial distribution of the E-field inside the chamber, also load or reduces the Q factor in a similar fashion to the resonant dipole. Each of these probes couple a small amount of energy out of the test field. In addition, they have lossy transmission lines made up of carbon loaded teflon that serve to convey their detected dc signals to their instrumentation located outside the chamber. These lossy transmission lines increase the chamber's loss up to 5 dB at 2.0 GHz. However, this amount of loss did not seem to significantly influence the ability to determine the field level in the chamber, with or without the presence of the probes by using the reference receiving antenna. The field level simply was lower for the same net input power due to the loading effect of the probes in the chamber.

The second test used to evaluate the loading effect was to place varying amounts of rf absorbing material inside the chamber. This was done to get an indication of just how much loading the chamber could tolerate before it fails to operate properly and/or large errors existed in determining test field level and EUT response. Progressively greater amounts of absorber were added until approximately 90 percent of the net input power was being absorbed (i.e., the chamber loss was increased by approximately 10 dB). The amount of rf absorber required was four pieces of 66 cm pyramidal high performance absorber 61 cm x 61 cm square. Results for tuner effectiveness, VSWR and chamber loss with absorber loading were shown in figures 2.18b, 2.22c, and 2.24. As indicated earlier, lowering the chamber Q reduces the test field level in the chamber for a given net input power. Inserting the 4 pieces of absorber in the chamber lowers the field considerably as shown in figure 3.3. This figure compares the maximum E-field strength in the test volume defined by the 7 probe matrix inside the empty chamber with the field strength after the chamber is loaded with the 4 pieces of absorber.

In summary, the following observations can be made from the data obtained (figures 2.18b, 2.22c, 2.24 and 3.3). Lowering the chamber Q:

1) decreases the effectiveness of the tuner (lower Max/ in ratio),

2) improves the VSWR of the transmitting and receiving antennas,

3) increases the chamber loss and hence increases the rf power required to obtain test fields of the same level,

4) increases the uncertainty in determining the test field level and EUT response (indicated by the larger variations in the E-field data obtained with absorber, figure 3.3), and

5) decreases the spatial, statistical E-field uniformity.

In conclusion, the following guidelines are suggested. Inserting the EUT should not lower the maximum or average received power from the chamber's reference antenna for the same net input power into the chamber (before and after inserting the EUT) excessively. If these ratios, net input power/received power(max or ave), increase more than 6 dB, or if the tuner's average effectiveness decreases to less than 20 dB, use of the reverberation chamber is not recommended.

4.0 Performing Immunity Measurements

4.1 Planning the Measurements

A number of considerations are important in planning the measurements, writing the test plan, and documenting the test results. One is the amount of data required to accurately characterize the EUT. Equipment susceptibility to EMI is primarily determined by the degree to which the interference field couples into and interacts with the equipment's components. This undesired coupling is influenced by a number of equipment parameters such as: input/output, power line, and circuit lead impedances and lead lengths; impedances of circuit components (especially those terminating lead wires); type of circuit components (particularly active components); and amount and type of EMI shielding and filtering used. The susceptibility of any particular equipment is usually a function of frequency, suggesting resonance effects within the equipment with its input/output leads and other interconnected equipment. These resonances may be caused, for example, by the reactance of the connecting leads acting as an antenna, coupling with the input impedance of the terminating circuit components. The quality factor (Q) of such a resonant circuit determines the maximum spacing or increment between frequencies at which susceptibility tests must be performed. Automated systems such as required by the reverberation chamber test methods are (by their digital nature) discrete frequency systems. The number of test points one can obtain using such a system are limited by the memory or storage capacity of the computer, the measurement system bandwidth, and the measurement time constraints. Thus, care must be exercised in choosing frequency and amplitude measurement intervals compatible with the test system and the number of test points required.

A second consideration is the test-field time duration versus reaction time of the EUT. Some EUTs have components with relatively slow thermal time constants. This equipment must be exposed to test fields with sufficient duration to allow reaction and interaction; otherwise susceptibility tests may not be true indicators of the equipment's vulnerability. For example, thermocouple devices used to simulate electro-explosive devices may require one to two seconds exposure time for maximum response. EUT soak time requirements influence the approach (section 4.2) selected for performing the tests using the reverberation chamber method.

Another important consideration relates to the need to simulate as closely as possible "real world" operating conditions. Ideally, susceptibility tests should be performed with the EUT connected and operated in its operational environment. Since this, most likely, is not possible, these operational conditions should be carefully simulated. This normally includes making certain the EUT is tested with its wiring harness in the same configuration (as nearly as possible) as when in actual use. (Actually, one of the advantages of the reverberation chamber method is that the test results are independent of EUT wiring harness , input/output and power lead orientation.) In addition, all connecting leads should be terminated with equivalent impedances as when in actual use. Failure to simulate these conditions can result in data that are misleading. An additional problem is the EUT-antenna-enclosure interaction that exists inside any shielded enclosure. Antenna radiation or receiving characteristics are altered when enclosed inside a shielded environment. One should realize that the EUT always interacts somewhat with the exposure field in any environment. What is difficult is sorting out the normal open-field scattering effect from the unknown perturbation effects of the EUT-antenna-enclosure interaction that is typically ignored in shielded room susceptibility testing. Efforts to quantify this effect for reverberation chamber obtained results are discussed in section 5.

How to sense and telemeter the performance of the EUT from the test environment without perturbing the EUT, the test environment or sensitive test equipment is another important consideration. This is usually done by using either fiber optics lines or "invisible" wire [13] (carbon impregnated Teflon) with appropriate readout devices.

Finally, one obvious purpose for performing susceptibility tests is to determine EUT compliance with pre-established performance criteria. For production item sampling, a worst case EMI exposure environment with pass-fail criteria may be appropriate. However, for engineering development of EMI-hardened equipment or for correcting EMI problems discovered in existing equipment, diagnostic testing is needed. This type of testing requires knowledge of the exposure field parameters, such as: frequency, repetition rates, and wave shape of test signal; type and percent of modulation imposed; and polarization, amplitude and signal waveform time variations. These parameters must be carefully selected, as part of the test plan, controlled, and (for some tests) statistically characterized for the testing to be meaningful. One obvious limitation of the reverberation chamber method for susceptibiltiy testing is the loss of polarization information. However, this is in part compensated for because worst case response characteristics of the EUT can be determined without repositioning or orienting the EUT in the reverberation chamber since the test field is rotated around the EUT. If carefully controlled tests are performed, resonances and susceptible EUT circuit components can be determined, from which cause and effect relationships can be established. These can then be modified or eliminated to improve the immunity of the EUT. Another important consideration in performing diagnostic testing is the desirability of determining how the EMI is coupled into the EUT. This requires separating, if possible, the sources of interference reception, such as EUT input/output and power line leads, leakage through the EUT case housing, or internally generated and coupled EMI. This can be achieved by a systematic process of shielding and filtering various leads and functional sections of the EUT's circuit, etc., while conducting the susceptibility tests.

4.2. Measurement Approach (Tuned vs. Stirred)

Two approaches are used for performing EMC measurements using the reverberation chamber. The first approach, mode tuned, steps the tuner at selected, uniform increments, permitting measurements of the net input power, reference antenna received power, field measuring probe response and the EUT response at each tuner position. This allows corrections and normalization of the received power, field measurements and EUT response to be made for variations in the net input power to the chamber. These variations are due to changes in the input VSWR of the transmitting antenna as a function of the tuner position. The number of tuner steps per revolution that must be used is a function of frequency and chamber Q. Typically, at least 200 steps or more are required to provide sufficient sampling to accurately determine the statistical parameters of the test field and EUT response (maximum and average amplitudes). If the sample size is too small, the fidelity of the measurements suffers and true maxima, minima, etc. are not recorded. The mode tuned approach also allows the operator to select long test field exposure times as needed to accommodate some EUT response times.

The second approach, mode stirred, rotates (steps) the tuner continuously while sampling the reference antenna received power, field probe response and EUT response at rates much faster than the tuner revolution rate. These measurements are made using a spectrum analyzer, diode detectors, and "smart" voltmeters with their own microprocessors capable of data storage and calculation of statistical functions such as mean values and standard deviations. The mode stirred approach allows large data samples (up to 9,999) for a single tuner revolution. Tuner revolution rates are adjusted to meet EUT response time and output monitor response time requirements. Typical revolution periods are from 1 to 12 minutes. This large sample, as compared to mode tuned, improves the accuracy in determining the statistics of the measured parameters, however, at the expense of increased uncertainty due to failure to correct for net input power variations.

Hence a trade-off exists between mode tuned and mode stirred operation. An examination of figure 2.22 suggests this trade-off occurs approximately between 1-2 GHz. (i.e., The mode tuned approach would be more accurate below 1-2 GHz where the mode density is not as great and corrections can be made for variations in the net input power caused by large variations in the input VSWR of the transmitting antennas. Mode stirring is more accurate at frequencies above 1-2 GHz where VSWR variations in the transmit antenna as a function of tuner position are small and large data samples of the test field and EUT response can be taken.)

4.3 Measurement System

4.3.1 Measurement Setup and Instrumentation Requirements

A block diagram of the basic NBS reverberation chamber EMC measurement system is shown in figure 4.1. The test field is established by means of rf source(s) connected to transmitting antenna(s) placed inside the chamber. Antennas used are discussed in section 2.2.5. Modes excited inside the chamber are then tuned or stirred by rotating the mode tuner which functions as a field-perturbing device. The EUT may be placed anywhere convenient within the chamber provided no point on the EUT is closer than 1/2 meter to any wall, or ceiling. Placement relative to the floor is dependent upon a number of factors including intended use configuration relative to ground-planes etc., and should be specified by the test plan. Test, power, and control cables are routed to appropriate monitors, etc., outside the chamber via shielded or filtered cables and feed-through connectors, high resistance lines, and fiber optic lines as required to prevent leakage of fields to the outside environment. Note that a precision 10 dB attenuator is used with the power detector or spectrum analyzer, whenever possible, to measure the receiving antenna power. This is done to minimize impedance mismatch with the receiving antenna. The calibrated bidirectional coupler at the input to the transmitting antenna allows measurements of the net input power so corrections can be made for changes in net input power resulting from antenna-rf generator impedance mismatch and rf generator output variations that occur during the rotation of the tuner. As referred to earlier, these corrections are made when using the mode tuned measurements approach for each incremental change in tuner rotation. For mode stirred, the net input power is measured only at the beginning of the measurement cycle. Details of how the measurement cycle proceeds under computer control, how the data are managed, recorded, and processed for presentation are contained in the next section describing the software used for these functions.

4.3.2 Software Requirements and Measurement Procedures

The computer code used in the evaluation of the reverberating chamber has evolved from simple routines that record only the measurement data to the present complex programs that have abilities to recover from many common system failures and operator errors. The more sophisticated programming is made possible by using modern laboratory computers containing large amounts of memory. The primary function of recording the measurement data however, remains unchanged and is outlined in this section, with some discussion of the supporting activities and refinements.

A general overview of the software is shown in figure 4.2. The major tasks of accumulating data using the two primary methods (mode tuned and mode stirred), saving the measured results, and preparing the data graphics are shown. The measurement routines are supported by the module entitled System Calibrations. The data library is not actually program code, rather it indicates data storage that is available to the Data Graphics program and is added to by the measurement programs. Two major programs, detailed below, are used to implement the measurement approaches. They are quite different in how the instrumentation is programmed and the data managed and will be discussed separately. The basic computer code defining these measurements is listed in appendix A. The listings contain the details of the measurements as shown in figures 4.3 and 4.4. The instrument control modules have been omitted to avoid excessive detail.

Mode-Tuned Approach

The flow diagram for the mode-tuned measurement program is given in figure 4.3. This diagram is used to assist in guiding the operator systematically through the measurement procedure.

Step 1. Place the EUT inside the chamber and access at as required for operation and performance monitoring.

Details for placement of the EUT and accessing it are contained in sections 3.1, 4.1, and 4.3.1. The EUT should be placed at least one half meter away from the outer walls of the chamber unless specified in the test plan to simulate proximity to a ground plane.

Step 2. Connect the measurement system as shown in figure 4.1.

Step 3. Specify measurement and calibration parameters.

Calibration factors for the cables and directional couplers used must first be tabulated and stored in the computer for later access. All parameters used in the measurements are then specified using a menu of items from which the operator may select the values for the experiment. These parameters include: frequency range and increments, number of tuner steps, signal generator output level as required to obtain the desired field strength inside the chamber, the EUT output voltage considered as an upper bound for maximum safe EUT operation, and an estimate of the response time of the EUT. The experiment description, operator's name, and the system clock can be accessed in the menu also. When the operator is satisfied with the parameter values and exits the menu, these values plus all calibration values (e.g., cable loss, coupling factors, etc.) are tabulated for reference. The measurement hardware is then initialized and the measurement begins.

Step 4. Perform the measurement (automated measurement sequence).

The measurement sequence can be traced in figure 4.3. At the beginning of each test all the instruments are set to zero (if there is an internal auto-zeroing feature) or a reading is taken to determine the offset from zero with the field removed. These offset readings are then used to adjust the readings taken with the field applied. This should be done as often as needed to minimize errors resulting from zero drift.

It is important to have reached both mechanical and electrical stability at each step of the tuner before reading the instruments. As the mechanical time constant of the stepping motor and the chamber's tuner blades is typically much longer than the electrical response time of the measurement instrumentation or the EUT, the most efficient manner with which to collect the data is to minimize the movements of the tuner. Any given measurement usually involves a sequence of frequencies at which to measure the response of the device. This routine is designed to collect the data for all frequencies at each tuner step before moving the tuner to another location. The data is then rearranged at the conclusion of the measurements such that data from all tuner positions for a given frequency is together before it is processed for final graphic presentation.

After the instruments are zeroed and their offset voltages recorded, the rf power is applied and the response of all devices which could be damaged by excessive field strength is measured. This checking is done as rapidly as possible for each frequency and provides one level of protection for the system. Typically, the operator should specify power levels that are appropriate for the EUT(s) being tested. Then this test will detect only those conditions which cause an unusually high response.

With the initial checking done, the program then proceeds to read the remaining instruments in the system. These include power meters, digital voltmeters, spectrum analyzer, specialized data acquisition systems, and/or any other monitoring device being used.

As mentioned above, all frequencies of interest are measured before the tuner is moved to the next position. There are many possible ways to group this data and save it on a mass storage device. The approach used here is to maintain all the data for a given tuner step (or several steps) together in one file. This file can then be recalled and the data rearranged such that all the information for a given frequency is together. Saving the data frequently allows the measurement to be continued, without starting over, should the system lose power or a fatal error occur.

The routines necessary for operation of the instruments are, of course, unique to the device but some general concepts are useful to discuss:

a). The program should exercise some care to insure the validity of the readings. Most instruments will allow access to a status byte that will indicate many failures common to the device. This can be monitored during the read cycle and action taken if the measurement is not valid. Action is also necessary if the device fails to respond or hangs the interface bus. These situations may require operator assistance, but the program should be able to recover and repeat the operation if the condition is temporary.

b). Readings taken within the limits of the instrument yet too quickly for the rest of the system to respond, for instance the tuner may still be vibrating or the sensor may be slow to respond, will cause erroneous results. For these measurements where the field being monitored is generated by a cw signal of constant amplitude, the response of a device should settle to a constant value, provided the tuner has stabilized and the device has had enough time to respond. The computer should be able to determine when to accept the reading based on the factors mentioned. One method is to install fixed wait statements that guarantee steady conditions. A more dynamic approach is to monitor the device and compare readings until steady conditions are reached. This optimizes the already lengthy measurement by avoiding long idle times that may not be necessary. A refinement to simply comparing readings is to compare the averages of several readings grouped together, referred to as a running average. This has a tendency to smooth noise that may be on the signal and also to make comparisons of low level readings (near the noise floor) more stable.

Step 5. Correct the data by applying the system calibration values and zero field offset readings.

The correction factors are applied to the measured quantities at the time the data are taken and key items are calculated. These items are then stored in the memory for later use in compiling the data. Items may include incident and reflected powers to the transmitting antenna corrected for cable loss and coupling factors, power received from the reference antenna (corrected), etc. Care must be taken at the beginning of the measurement to assure that calibration factors and cable loss correction to be used match the physical setup.

At the completion of the last tuner position, with all the data residing in mass storage, the measurement routine is complete. The remaining tasks are independent programs, freeing the measurement system for other measurements.

Step 6. Compile the corrected data by frequency, normalize to a constant net input power (for example 1 watt), perform the statistical calculations and present final results.

Normalization of the corrected measurement data for determining: a) the E-field in the chamber, and b) the EUT response, for a constant net input power is done for each tuner position. First the corrected net input power is determined and compared to the desired normalized value. The difference is then used to shift the corrected received power measurements and EUT response measurements as if the actual net input power had been the desired normalized value. This may involve a simple linear extrapolation as is the case for linear detectors, or it may require calibration of the nonlinear response characteristics of the received power detectors and/or EUT monitors thus resulting in appropriate corresponding nonlinear corrections.

The statistical calculations are performed using the corrected, normalized data. These calculations include the maximum, average, and minimum values as appropriate, of the desired parameters (net input power, received power, EUT output response, etc.). The calculations are made using data sets obtained by using the corrected normalized data at the selected number of descrete tuner positions for one complete revolution of the tuner, at each frequency of interest. These result are then, typically, presented in graphs as a function of frequency.

Mode Stirred Approach

The mode-stirred measurement (figure 4.4) begins in a similar manner to the mode-tuned discussed above. The automated measurements sequence of events is somewhat different and hence some of the parameters necessary for performing mode-stirred measurements differ from mode-tuned.

Step 1. Place EUT inside the chamber and access it as required for operation and performance monitoring.

This is the same as for mode tuned.

Step 2. Connect the measurement system as shown in figure 4.1

This step is similar to the setup for mode tuned except the spectrum analyzer is used to measure the reference antenna received power and the EUT monitors must be fast sampling devices such as "smart" voltmeters referred to earlier.

Step 3. Specify measurement and calibration parameters.

These parameters are similar to the mode tuned case with the following two exceptions:

a) The specification of revolution time for the tuner determines the sample size and sampling parameters associated with the EUT monitoring equipment. Tuner steps (sampling size) are now given as a function of time for one complete revolution of the tuner from which the number of samples that will be taken during that single revolution, for each of the sampling instruments, is determined. These numbers require careful timing trials prior to automating a mode-stirred measurement. The instruments used for the tests detailed in this report, "smart" digital voltmeters, are capable of performing statistical operations on a large number of samples (up to 9999) using a single trigger command. This feature is very convenient for this type of measurement but requires that the number of samples needed to synchronize rotation time of the tuner and total sampling time of the voltmeter be known prior to triggering the measurement. The time required for taking each sample voltage varies slightly with the amplitude of the signal measured. This makes it difficult to estimate accurately the total time required for any given number of samples. Approximations are used and the program adjusts the sample count to insure the correct sampling time for a complete revolution. The sampling should be completed as near to the end of the tuner revolution as possible to avoid weighting the statistics with an incomplete data set or data taken as the tuner begins a second revolution. Typical rates for tuner rotation are in the range of 1 to 12 minutes per single revolution.

b) The signal generator output level is now a range of values because this program has the ability to search for an optimum response of the device. The range of response values is also accessible in the mode-stirred menu and gives the operator control over minimum readable output from the EUT and also the level considered as the upper safe limit. The program will attempt to keep power levels adjusted such that the response is at some point above the minimum and never above a maximum.

Sometimes it is advantageous to monitor the EUT response using analog devices such as an xy recorder. If care is taken to insure that the response time of the recorder is short compared to the sampling rate or rotation rate of the tuner, the EUT output can be monitored in real time, thus allowing optimization of the sample rate to correspond to the EUT response time. Care must be taken to insure adequate sample time, otherwise the EUT response will be clipped yielding inaccurate results. This condition is easy to detect from the analog output plots and hence avoid.

When the operator is satisfied with the parameter values and exits the menu, these values plus all calibration values (e.g., cable loss, coupling factors, etc.) are tabulated for reference. The measurement hardware is then initialized and the measurement begins.

Step 4. Perform the measurement (automated measurement sequence)

The measurement sequence is shown in figure 4.4. At the beginning of each test all the instruments are set to zero (rf power is off), if possible, or the zero offset is recorded the same as for the mode-tuned approach. The rf power is then applied at the lowest specified level, the tuner motion is activated, and the EUT response is monitored. This first measurement attempt, at each specified frequency, results in a search for a threshold response from the EUT. If the EUT's response is below the preselected level, the rf power is increased in 1 dB increments and held constant allowing the tuner to rotate a few degrees, while searching for the threshold level. If the threshold value for the EUT's response is not reached, the generator level is increased again and the searching process repeated until the threshold level is reached or the maximum range selected for the generator output is achieved. Upon finding an acceptable power level, the instruments are triggered to begin a measurement cycle. Typically the instruments used include "smart" digital voltmeters as mentioned earlier and a spectrum analyzer looking for a peak response from the reference antenna. Any specialized detecting device would also be included. The response of the EUT is constantly monitored via a second fast sampling voltmeter (in addition to the "smart" voltmeter doing the statistics) to protect it from overload. If, during the test, the response should exceed the maximum safe value so that the power level is decreased or any other error condition is detected, the program will remember the correct power level to be used as the measurement is restarted.

At the time all the instruments are done sampling, the program checks to see if the tuner completed a full revolution before the measurements (sample) were finished. A comparison of the times taken for the tuner revolution and each meter's total sampling time is made. If these values agree to within a given tolerance and no other errors were detected, then the numbers are assumed to represent a valid measurement. On the other hand, if these conditions are not met, the sampling parameters are adjusted and the entire measurement process is repeated for the same frequency. Special care taken in the preparation of these sample parameters, as mentioned earlier, will minimize the need for repeat measurements.

The results from all the instruments are now read into the computer, corrected using the appropriate calibration factors and the necessary calculations are made. This includes the statistical parameters for the EUT monitored data, as determined by the "smart" voltmeters, and the peak value of the received power from the reference antenna as measured using the spectrum analyzer. Caution must be exercised if the test field is modulated since this may influence the accuracy of the measurement results depending upon the detector(s) response characteristics.. The reference antenna received power data can be used to determine a normalized response for the EUT based upon a constant test field level as a function of frequency if desired. The net input power delivered to the chamber is measured after the acceptable power level is established at the beginning of the measurement cycle, just prior to triggering the "smart" voltmeters. These measurements may then be used to normalize the data to an equivalent constant input power level preselected for all test frequencies if desired. The entire process is then repeated until all frequencies have been measured.

The process by which the statistics are derived for the parameters monitored by the "smart voltmeters" consists of the following steps: 1) the measured analog data is converted to digital form; 2) the first data value is stored for future reference; 3) the second and subsequence data values are compared to the previous data values to determine maximum, minimum, and the running total values; 4) at the conclusion of the data collection, (completion of the data sample) the running total is divided by the sample size to calculate an average value for the data set; and 5) finally, the maximum, minimum, and average values stored in the "smart" voltmeter are transferred upon command to the computer for mass storage and future use as required.

Step 5. Compile the corrected data and present final results.

Data obtained using the mode stirring approach is not normalized at each tuner position. Corrections applied to this data to normalize it to a specified value of net input power must be applied to the maximum, average, and minimum values as determined by the "smart" voltmeters (EUT and other monitored responses) or the maximum value (reference received power) as determined by the spectrum analyzer. Correction made to the data for cable loss, etc., must also be made in a similar way. After these corrections are made, the data is compiled by frequency and presented typically in graph form usually showing only the maximum values as a function of frequency. For example see figures 5.15 and 5.16.

5. Experimental Test Results

5.1 Correlation of Results to Anechoic Chamber Tests - Some Examples

This section describes efforts to estimate a "correlation factor" between reverberation chamber and anechoic chamber obtained results. This was done first for reference standard EUTs and then for an EUT more typical of operational equipment. Tests were performed using the NBS reverberation chamber and a 4.9 m x 6.7 m x 8.5 m anechoic chamber also located at NBS. The EUTs included in this study are: 1) a one centimeter dipole probe antenna (200 MHz to 18 GHz), 2) a ridged horn antenna (800 MHz to 10 GHz), 3) a series of rectangular coaxial transmission line (TEM) cells with apertures, (200 MHz to 4000 MHz), and 4) a modified 7.0 cm (2.75 ") folded fin aircraft rocket, (FFAR) (200 MHz to 12.0 GHz).

5.1.1 Description of Anechoic Chamber Measurement System

A block diagram of the NBS anechoic chamber EMC measurement system is shown in figure 5.1. The test field is established inside the chamber by means of an rf source connected to a standard gain transmitting antenna. This "standard field" is computed from [22]

$$E = \frac{\sqrt{30 \, P_{net} G}}{D} \, , \tag{14}$$

where P_{net} is the net power in watts delivered to the transmitting antenna, G is the effective gain for the transmitting antenna, and D is the separation distance in meters. Equation (14) assumes far-field conditions for a field point on axis of the transmitting antenna so that G is the maximum power gain.

The net power, P_{net}, is determined using calibrated power meters and bidirectional couplers from the expression

$$P_{net} = P_{inc} \, CR_F - P_{ref} \, CR_R \tag{15}$$

where P_{inc} is the forward incident power, P_{ref} is the reverse reflected power measured on the sidearm of the coupler, and CR_F and CR_R are the forward and reverse coupling ratios for the coupler referenced to its output port.

The transmitting antennas used are open ended waveguides (200 to 500 MHz) and standard gain horns (500 MHz to 18 GHz).

Comparisons of the response or susceptibility characteristics of EUT (or antennas) obtained using an anechoic chamber and a reverberation chamber are typically made in terms of peak values. The main reasons for this are that typically the EUT's worst case performance or susceptibility is desired, and the practical consideration of the difficulty in obtaining a true average response for an EUT from anechoic chamber data. Even determining the EUT's peak response in an anechoic chamber (depending of course upon how well behaved the EUT radiation pattern characteristic is) can require considerable measurements involving complete pattern measurements.

5.1.2 Measurement of the Peak Response of a 1 cm Dipole and a Ridged Horn

A comparison of the peak output response data obtained for the 1.0 cm dipole using the NBS reverberation and anechoic chambers is given in figure 5.2. Note that the probe output response in the anechoic chamber is greater, in general, by about 2.5 dB than its output in the reverberation chamber. This suggests that the correlation between the results may be related to the EUT's gain characteristics in the two chambers (i.e., the gain of the dipole probe in free space is approximately 2.5 dB). Determination of a far-field gain for a complex receptor (for example the EUT described in section 4.3.4) is extremely difficult. Therefore, a simple, well defined broadband receiving antenna (a ridged horn) was used as an EUT to repeat similar tests performed for the 1 cm dipole. The horn is designed to operate in the frequency range 800 MHz - 10 GHz. For these measurements in the anechoic chamber, the peak response (peak received power) of the horn occurs when the horn is bore-site aligned and polarization matched with the source antenna. These measurement results were then compared with the horn's peak received power in the reverberation chamber with the same level exposure field. The results are shown in figure 5.3a. Note that the horn's response is greater in the anechoic chamber. To see if this difference corresponded to the difference in the gain characteristics of the horn in the anechoic chamber, as compared to that in the reverberation chamber, the horn was calibrated to determine its far-field gain in the frequency range 800 MHz - 10 GHz. These results are shown in figure 5.3b. Again, note the general agreement between the difference in the horn's response measured in the two facilities and the horn's far-field gain.

5.1.3 Measurement of RF Coupling Through Apertures in TEM Lines

Measurements were made using the reverberation and anechoic chambers to evaluate the rf coupling through apertures cut into a series of TEM cells or transmission lines. Three TEM cells were used. Similar models (EUTs) have been used for evaluating shielding effectiveness of connector assemblies [23]. Electromagnetic energy coupled through the aperture in the TEM cell when exposed to the test field excites the fundamental TEM mode inside the cell. This results in rf power conducted to the cell's output ports which can then be measured. These results are compared with the theoretically predicted values based upon a planar field exposure to determine degree of correlation. The results obtained for one of the TEM cells, shown in the photograph of figure 5.4, are given in figure 5.5. The dimensions for this cell are 12 cm x 18 cm x 36 cm with a 5.1 cm x 5.1 cm aperture centered in the top of the outer conductor. The theoretically predicted peak coupling for a uniform field exposure is also shown on figure 5.5 [24]. Measurements were not made in the anechoic chamber at frequencies below 500 MHz because of the limitations of the anechoic chamber measurement system. The theoretical peak values should be essentially the same as the measured values in the anechoic chamber. Again, the anechoic chamber peak data are generally higher than the peak reverberation chamber data. Also, the average reverberation chamber data are approximately 7-8 dB lower than the peak data, similar to both the 1 cm dipole and ridged horn results.

Results obtained for the second cell, shown in figure 5.6, are given in figure 5.7. The dimensions for this cell are 12 cm x 12 cm x 24 cm with a 3.1 cm diameter aperture. The results are similar to those shown for the larger cell. Results obtained for the third cell, shown in figure 5.8, are given in figure 5.9. The dimensions for this cell are 3.0 cm x 6.0 cm x 11.4 cm with a 1.4 cm diameter aperture centered in the top of the outer conductor. Again the results are similar.

5.1.4 Measurements of the EM Susceptibility of a Modified 7.0 cm Folding Fin Aircraft Rocket (FFAR) [25].

A 7.0 cm diameter FFAR was modified with a thermocouple element to sense the response of the rocket's inserted electro-explosive device (EED). This was done to allow measurement of the rf current coupling into the EED's bridge wire circuit when the rocket is exposed to an rf field. The rocket was also modified with a 1.27 cm plastic spacer at the base of its fin (on the tail section) to increase the rf coupling to the bridge wire circuit. This lessened the requirements for high rf power to generate fields sufficient to perform these measurements. This modification was justified, realizing the purpose of this study was to compare susceptibility results obtained for the rocket in different environments and not to simply evaluate an EUT's susceptibility to EMI. Photographs showing the rocket placement inside the NBS reverberation chamber and the NBS anechoic chamber are shown in figures 5.10 and 5.11. Measurement results of the rocket's thermocouple peak output current resulting from rf coupling as a function of frequency are shown in figures 5.12a and 5.12b. These data were obtained using exposure fields normalized to 10 mW/cm^2 in each of the chambers. The anechoic chamber data were obtained by rotating the rocket in azimuth in a planar far-field using both vertical and horizontal polarizations. The rocket was rolled a few degrees around its axis before each azimuth cut. Sufficient roll angles were used to determine the peak response. Examples of pattern data obtained in the anechoic chamber at three selected frequencies are shown in figure 5.13. A total of 719 patterns were obtained in the anechoic chamber from which the peak response at each frequency was determined. These data were then used to plot curve A of figure 5.12a. Curve A (anechoic chamber data) indicated greater response or more susceptibility, except at one frequency (1800 MHz), than curve B (reverberation chamber peak response). Again, the proposed explanation for this is the difference between the gain characteristics of the rocket's response in the anechoic chamber (for example see figure 5.13) and its gain characteristics in the reverberation chamber. The rocket gain is lost in the reverberation chamber. Figure 5.12b shows the difference between curves A and B for figure 5.12a.

5.2 Comparison of Results Between Reverberation Chambers

Measurements were made of the EM susceptibility response of three different EUTs, using two additional, similar, but different size reverberation chambers. These measurements were made to give an indication of the repeatability in measurement results obtained using the same technique (reverberation chamber methods) but with totally different facilities. The second and third reverberation chambers are located at the Naval Surface Weapons Center, Dahlgren, Virginia. These chambers were made from a single large shielded enclosure partitioned into two compartments with a removable center panel. The two chambers consist of: 1) the half chamber, 3.51 m x 5.18 m x 5.86 m in size using a little over half of the full enclosure, and 2) the full chamber, 3.51 m x 5.18 m x 10.82 m in size, using the full enclosure. The NSWC enclosure was constructed of continuously welded steel sheeting similar to the NBS enclosure. Two basic insights are provided by a comparison of results obtained from the evaluation of these different enclosures. First, that the input power requirements of a chamber is a function of its size and can be estimated based upon the calibration of a chamber of similar construction. Second, susceptibility test results obtained for the same EUT in different reverberation chambers are comparable. These conclusions are demonstrated in figures 5.14 to 5.17. Figure 5.14 shows a comparison of the fields inside the NBS and NSWC chambers calculated from the chamber's reference antenna received power measurements and then measured by a calibrated 1 cm dipole probe. The net input power was normalized to one watt for all three chambers. Note that the field inside the NBS chamber is approximately 4 dB stronger than the NSWC half chamber and 6 dB stronger than the NSWC full chamber. Recall that the power density inside a second chamber can be estimated from a calibrated chamber by using (9). The ratio of the average power densities for the NBS to NSWC full size chamber for the same net input power (see section 2.1) was 3.22. This is equal to approximately 5 dB, a little less than that indicated by comparing figures 5.14a and 5.14c, but still within reason.

The second point of obtaining comparable susceptibility results using different chambers is demonstrated in figures 5.15 to 5.17. These graphs show the comparison in measuring the responses of the NBS 1 cm dipole probe and a rectangular single ridged horn to a normalized 37 dB V/m field inside the three different chambers and the peak response of the 7.0 cm FFAR to a normalized 10 mW/cm^2 power density inside the NBS and the NSWC half size reverberation chambers. In general, the agreement is within measurement tolerances except at 200 MHz for the FFAR. This frequency approaches the lower limit for using the reverberation chambers and is also where the FFAR is most susceptible and hence where one would expect the greatest difference.

6. Summary and Conclusions

6.1 Conclusions Drawn From Study

1. The practical lower frequency limit for using the NBS enclosure as a reverberation chamber is approximately 200 MHz. This lower limit is due to a number of factors including insufficient mode density, limited tuner effectiveness, and ability to uniformly excite all modes in the chamber. These factors are a function of both chamber geometry and size. Increasing the inside dimensions of the chamber will lower the useful frequency limit in an approximately proportional manner.

2. Spatial variations in the E-field maximum and average values determined in the chamber's test volume are:

Frequency (MHz)	Variation in Measured E-Field
200	<± 8 dB
500	<± 5 dB
1000	<± 3 dB
2000	<± 2 dB

These data were determined using the mode tuned approach with 200 tuner increments for one complete tuner revolution. The limitation for determining the spatial E-field variation is most likely due to the increasing mode density and hence field complexity in the chamber as a function of frequency and the insufficient sampling of the field resulting from the limited number of tuner positions used. The spatial E-field variations should decrease less than 2 dB at frequencies above 2 GHz if sufficiently large data samples are taken.

3. Using a combination of antennas within their specified design frequency ranges for transmitting and as reference receiving antennas inside the chamber is preferred to the use of a long wire antenna. This is apparent because of the lower VSWR and greater efficiency in exciting the chamber and coupling energy from the chamber.

4. E-field data obtained using the mode stirred approach with the chamber empty have significantly less amplitude variations with frequency than data obtained using the mode tuned approach, particularly at frequencies above 1-2 GHz (e.g., <3 dB rather than <6 dB. Compare figure 2.26 to figure 3.3.) This implies that the mode stirring method is superior for some applications above these frequencies. This is significant since the stirred method is much simpler and faster to use. In comparing the two methods it is interesting to note the difference in the amplitude of the maximum fields at frequencies below 1-2 GHz. The mode tuned method is more accurate at these frequencies for determining the absolute amplitude of the test field since it allows for corrections due to changes in antenna VSWR. Because of these observations and other supporting data, the best results (accuracy versus measurement time considerations) for the NBS reverberation chamber can be obtained using the following approaches and tuner positions for susceptibility testing:

Frequency Range	Method	# Tuner Positions or Samples
0.2-1.0 GHz	Mode Tuned	200
1.0-2.0 GHz	Mode Tuned	400
>2.0 GHz	Mode Stirred	5000

5. Lowering the Q of the enclosure: a) increases the rf power required to obtain the test field, b) increases the uncertainty in determining the test field level, and c) decreases the spatial, statistical field uniformity.

6. The statistically determined average wave impedance of the EM field in the chamber is approximately that of free space (377 ohms), thus confirming the validity of (10).

7. The maximum E-field is approximately 7 to 8 dB greater than the average E-field.

8. Scattering from the EUT does not seem to influence the statistical, spatial E-field distribution within the chamber.

9. Multiple source excitation (from more than one location) improves the spatial E-field distribution slightly, but not enough to justify additional hardware requirements and the additional rf power needed to compensate for the loss in the additional input transmission line required.

10. Energy is conserved in the chamber (i.e., power coupled from the chamber via loss in transmission lines, antennas, EUT, physical support materials, etc., reduce the power density in the chamber. Thus it is good practice to remove all that are not essential to the tests from the chamber.

11. The chamber (NBS) continues to operate (as a reverberation chamber) with loading that reduces the Q significantly (up to 90% of the total energy absorbed), however, with significant loss in measurement accuracy.

6.2 Summary of Measurement Uncertainties

6.2.1 Determining the Field Strength Inside the Chamber

Recall from section 2.3.1 that the susceptiblity/vulnerability test field established inside the chamber can be expressed either in terms of an "equivalent" power density (8) or an "equivalent" E-field strength (10). An estimate of the uncertainties in each of these quantities can be obtained by analyzing the contributing parameters involved in each mode-tuned and mode stirred approaches respectively, within their appropriate frequency bands. Five major categories are identified. The first is the uncertainty in determining the received power from the chamber's reference antenna. This is broken up into four components: namely, cable loss, attenuator calibration, reference antenna efficiency and power meter or spectrum analyzer measurements uncertainties. Values shown are typical of estimated uncertainties stated for these type of measurements and instruments.

The second category is the impedance mismatch error that can occur between the reference receiving antenna(s) (source) and the power detector(s) (load). The actual power delivered to the load is a function of the impedance match between the source and load, with maximum power transfer occurring when a conjugate impedance match exists.

Power transfer between a source and a load is given as

$$P_f = \begin{array}{c}\text{fraction of maximum} \\ \text{available power absorbed} \\ \text{by the load}\end{array} = \frac{(1 - |\Gamma_S|^2)\,(1 - |\Gamma_L|^2)}{|1 - \Gamma_S \Gamma_L|^2} \tag{16}$$

where Γ_S and Γ_L denote complex reflection coefficients. The magnitudes, $|\Gamma_S|$ and $|\Gamma_L|$ can be obtained from the appropriate VSWR by the expressions

$$|\Gamma_i| = \frac{\text{VSWR} - 1}{\text{VSWR} + 1} \quad , \qquad i = S \text{ or } L \ .$$

The VSWRs for the reference antennas (sources) and power detectors (loads) used in the NBS reverberation chamber are given in table 6.3. These values were used to calculate the estimated uncertainties shown for the mismatch error in tables 6.1 and 6.2. Note that different average and maximum values are given.

The third category of error, referred to as mixing or sampling efficiency, is divided into two parts. The first part relates to the ability to obtain a uniform spatial field distribution (statistically) inside the chamber and to effectively destroy the polarization characteristics of the exposure field. (i.e., the statistically determined response characteristics of the EUT and chamber reference antenna are independent of their directional properties.) The second part is the uncertainty due to limiting the number of tuner positions per revolution when performing the measurement. This source of uncertainty is different when determining the average as compared to the maximum field as shown in the tables. Data shown in figure 2.27 and table 6.4 were used in obtaining these estimates.

The fourth category of uncertainty relates only to determining the equivalent E-field strength in the chamber from the equivalent power density. Recall that (10) assumes that the equivalent wave impedance inside the chamber is 120π ohms. In reality this is not true as was shown in figure 2.25. This figure was then used to provide an estimate for this error taking into account that a significant amount of data obtained to date indicates that peak fields are approximately 7-8 dB greater than the average field strength inside the chamber (see section 2.3.2). i.e., An examination of figure 2.25 shows values of wave impedance as large as 1600 ohms at frequencies below 500 MHz when the maximum E-field was measured. This would require a large correction, up to 6.3 dB. However, experience indicates that a well behaved relationship (7-8 dB difference) exists between the measured peak and average values of the E-field. This suggests that the peak value of the wave impedance for maximum E-field inside the chamber decreases as the frequency increases thus lowering this source of error. These observations are reflected in the uncertainty estimates shown in the tables.

The fifth source of error occurs if one fails to correct for net input power variations due to the loading effect of the chamber on the VSWR of the source antennas. (See section 4.2 for more details.) Note that these corrections are made typically when using the mode tuned approach and hence are not included in the total or root-sum-square error estimates of table 6.1. They are shown on the table to provide insight to the estimated magnitude of error expected if this correction were not made. The basis for these estimates are the data shown in figures 6.1a and 6.1b. These figures show the average and maximum E-field strength measured inside the NBS reverberation chamber using an array of seven NBS isotropic probes. A comparison is shown between results obtained before and after the measurements were corrected for net input power variations and normalized for an equivalent constant net input power. Note from table 6.1 this error is the same order of magnitude as 2), the mismatch error between the receiving antennas and power detectors. This is as expected since the source and receiving antennas used in the chamber have similar VSWRs and the power detector (load) and generator VSWRs are also similar. This error is included in table 6.2 and estimated to be the same as for the receiving mismatch error.

The total (worst-case) uncertainties for each approach (mode-tuned, and mode-stirred) are shown at the bottom of each table. This uncertainty should be regarded as a conservative estimate. The probability of the true value of E_a being near the extreme of such worst-case uncertainty is small. This is because the probability of every error source being at its extreme value and in the worst possible combination is almost zero.

A more realistic method of combining uncertainties is the root-sum-of-the-squares (rss) method. The rss uncertainty is based on the fact that most of the errors are independent of each other and hence are random with respect to each other and combine like random variables. The rss method of combining random variables is justified by statistical considerations (beyond the scope of this report) which are also inherent in the reverberation chamber measurement methods.

Finding the rss uncertainty requires that each individual uncertainty be expressed in fractional form. The method of calculation follows the name - square the components, sum those squares and then take the square root. The results are shown at the bottom of tables 6.1 and 6.2.

6.2.2 General Comments on Error Analysis.

Some general comments on interpreting immunity measurement results uncertainties based upon the above experimental error analysis are appropriate.

1) The mismatch error at frequencies below 2 GHz, (particularly if corrections are not made for either the transmitting antennas or the receiving antennas mismatch looking into their source or load), will cause the field determination inside the chamber to be low. This also causes the EUT response results to be lower than they actually are. For example, the low frequency data of figures 5.15, 1 cm dipole, and 5.16, ridged horn, should be corrected (response increased) proportionally to the systematic offset error estimates show in tables 6.1 and 6.2. (i.e., 3.46 dB at 1.0 GHz and 1.66 dB at 2.0 GHz).

2) The wave impedance, when the peak response of an EUT is measured, appears to be higher than 120π ohms. This means that if the free space wave impedance of 120π ohms is used in determining the corresponding peak amplitude of the exposure field, there will be a systematic offset error resulting in too low a calculated E-field exposure value, or, since the actual E-field is higher than the calculated value this results in too high a EUT response indication for a specified E-field exposure.

3) The spatial variation in the measured, statistically determined E-field in the chamber resulting from a complete revolution of the tuner decreases from as great as ± 8 dB at 200 MHz down to less than ± 2 dB at 2.0 GHz. (See figure 2.27.) Logically, it is expected that this variation will continue to decrease as the frequency increases. However, high variations exist in the response data obtained for EUT at frequencies where the spatial E-field variations are small. This is probably due to the relatively large variations in the wave impedance as a function of tuner position. Some additional influence may be due to the mismatch characteristics of the antennas vs source and load as a function of frequency. A way to reduce this problem is to increase the number of frequencies at which data are taken (clustered around a particular frequency of interest) or increase the number of reference receiving antennas or probes used to determine the exposure field (for example see figure 2.27) and then average the data.

6.3 Measurement Technique Advantages and Limitations

Significant advantages do exist, as alluded to in the introduction, for using a reverberation chamber for EMC measurements. Specific advantages and limitations for which insight was obtain from this study include:

a) The ability to generate high level fields efficiently. For example, 1 watt net input power into the NBS reverberation chamber results in electric fields of approximately 70 V/m. This is approximately 1/10 the input power required to generate the same level field in the NBS anechoic chamber, assuming far-field separation distances.

b) Large test zones, for example up to 2/3 of the volume inside a reverberation chamber can be available excluding an area approximately 1/2 meter spacing to the walls.

c) Broad frequency coverage (from 200 MHz to at least 18 GHz in the NBS chamber).

d) Testing is cost effective. This is especially true in comparison to anechoic chamber testing. Significant savings are realized in two major ways. First, the facility installation and measurement system procurement costs for a reverberation chamber are significantly less than for an anechoic chamber. Second, the time required to perform a complete EMC analysis of an EUT should be much less using a reverberation chamber. Again, from our experience in evaluating the susceptibility of the 7.0 cm FFAR, it required approximately 1/10 the test time to obtain the reverberation chamber results as compared to the anechoic chamber results shown on figure 5.13.

e) The directional characteristics of antenna or EUT placed inside a reverberation chamber are lost resulting in an equivalent gain of unity.

f) The response of an antenna or EUT measured inside a reverberation chamber is less than when measured inside an anechoic chamber (open space) in proportion to its gain. Hence, it appears that the EUT's gain is the desired correlation factor. This implies that susceptibility criteria determined for an EUT using a reverberation chamber must include an additional factor proportional to the EUT's estimated maximum gain as a function of frequency.

g) The response of EUT to an electromagnetic field <u>after</u> it has penetrated the EUT's shield, appears to be equivalent in both the reverberation and anechoic chambers.

The advantages indicated above may well outweigh the disadvantages implied in items e and f, at least for some applications. The obvious trade off is one of measurement uncertainty that one can tolerate in determining the EMC/EMI characteristics of specific EUT and the inherent measurement uncertainties associated with determining the amplitude of the test fields inside the reverberation chamber.

7. Suggestions for Future Research Efforts

Because of the significant potential of the reverberation chamber method for performing immunity measurements, considerable interest has been expressed to further evaluate this technique with the intent of extending its range of applications. Specifically, the following suggestions are offered.

1) Evaluate the reverberation chamber measurement method for pulsed rf (down to 1 μs pulse duration) immunity testing, (i.e., experimentally investigate pulse dispersion characteristics of the chamber). Measurement studies are in progress at NBS under the sponsorship of the NSWC and RADC to complete this task.

2) Determine the feasibility of extending the use of the chamber from 18 GHz to 40 GHz. A plan exists to undertake such an effort in late 1985 at NBS under sponsorship of RADC.

3) Evaluate reverberation chamber excited as a TEM transducer, (i.e., determine the feasibility of consolidating a TEM cell and reverberation chamber into a single facility for testing from 10 kHz to 18 GHz and beyond). This item is suggested because of the unique potential of developing a single, shielded facility that could be used for EMC/EMV testing over the complete frequency range listed above. This task is also planned at NBS under RADC sponsorship.

4) Investigate the feasibility of using the reverberation chamber for multiple frequency immunity testing. This is of interest because such complex fields of multiple frequencies can exist in typical operational environments.

5) Investigate the use of the reverberation chamber technique for measuring shielding effectiveness of connectors (evaluate MIL STD 1344 measurement technique), shielding materials, and enclosures in comparison to other techniques. This suggestion is included with the objective of improving the state of art in shielding measurements and to determine if correlation or agreement exists between results obtained using the reverberation chamber method and other established techniques.

8.0 Acknowledgments

The work described in this report was jointly funded by the Naval Surface Weapons Center (NSWC), Dahlgren, Virginia; Rome Air Development Center (RADC), Griffiss Air Force Base, Rome, New York; and the National Bureau of Standards,(NBS), Boulder, Colorado. The authors express appreciation especially to John Bean, NSWC; Charles Blank, RADC; and Mark T. Ma, NBS for their support, helpful comments and editorial review. Acknowledgement is also given to John L. Workman for his assistance in performing many of the measurements included in this study.

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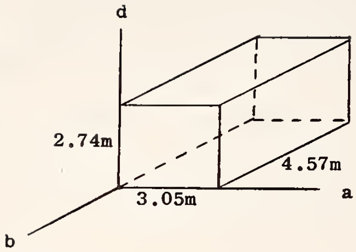
LIST OF FIGURES and TABLES

Table 6.1 Summary and estimates of measurement uncertainties for determining field strength inside NBS reverberation chamber - Mode Tuned (200 MHz - 2.0 GHz).

Table 6.2 Summary and estimates of measurement uncertainties for determining field strength inside NBS reverberation chamber - Mode Stirred (2.0 GHz - 18.0 GHz).

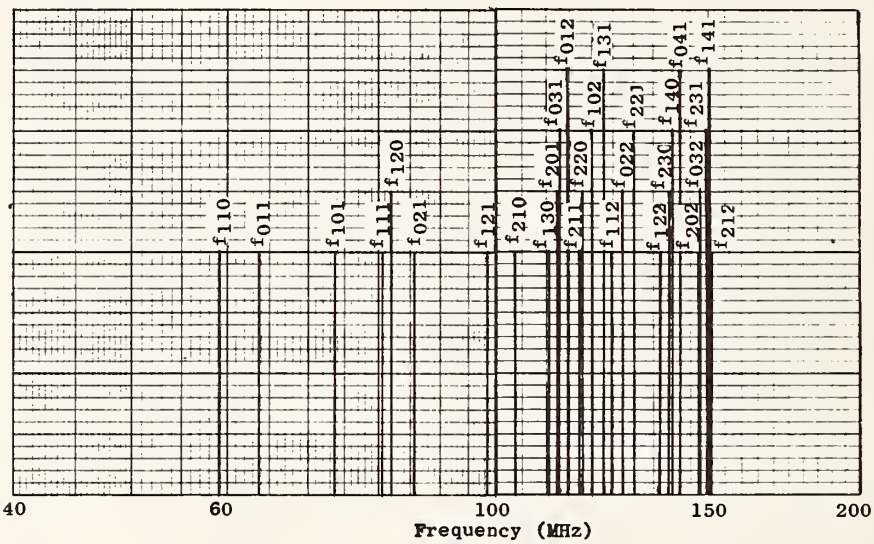
Table 6.3 Estimates of impedance mismatch uncertainties for received power measurements.

Table 6.4 Estimates of uncertainties due to limiting number of tuner positions (sample size).



$$f_{mnp} = 150\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2}$$

m,n,and p are integers



Distinct modes	Mode #	Frequency MHz	Distinct modes	Mode # f_{mnp}	Frequency MHz
1	110	59.13	33	222	161.16
2	011	63.83	34	320	161.49
3	101	73.59	35	240	164.05
4	111	80.58	36	013	167.48
5	120	82.02	37	321	170.51
6	021	85.48	38	042	170.95
7	121	98.62	39	150	171.32
8	210	103.69	40	103	171.44
9	130	110.07	41	241	172.94
10	201	112.57	42	051	173.00
11	031	112.66	43	113	174.55
12	012	114.30	44	023	176.87
13	211	117.26	45	232	177.08
14	220	118.25	46	330	177.38
15	102	120.03	47	142	177.89
16	131	122.93	48	151	179.86
17	112	124.43	49	123	183.58
18	022	127.66	50	302	183.73
19	221	130.31	51	331	185.64
20	122	136.81	52	312	186.64
21	230	139.18	53	250	191.33
22	140	140.20	54	203	191.44
23	041	142.25	55	033	191.48
24	202	147.18	56	213	194.23
25	032	147.25	57	322	195.10
26	231	149.56	58	242	197.23
27	141	150.51	59	052	197.28
28	212	150.80	60	340	197.50
29	310	151.15	61	133	197.71
30	132	155.25	62	251	199.01
31	301	157.37	63	410	199.44
32	311	160.76	64	223	202.38

Figure 2.1 Distinct frequencies of modes in NBS 3.05 m wide by 4.57 m long x 2.72 m high shielded chamber below 200 MHz.

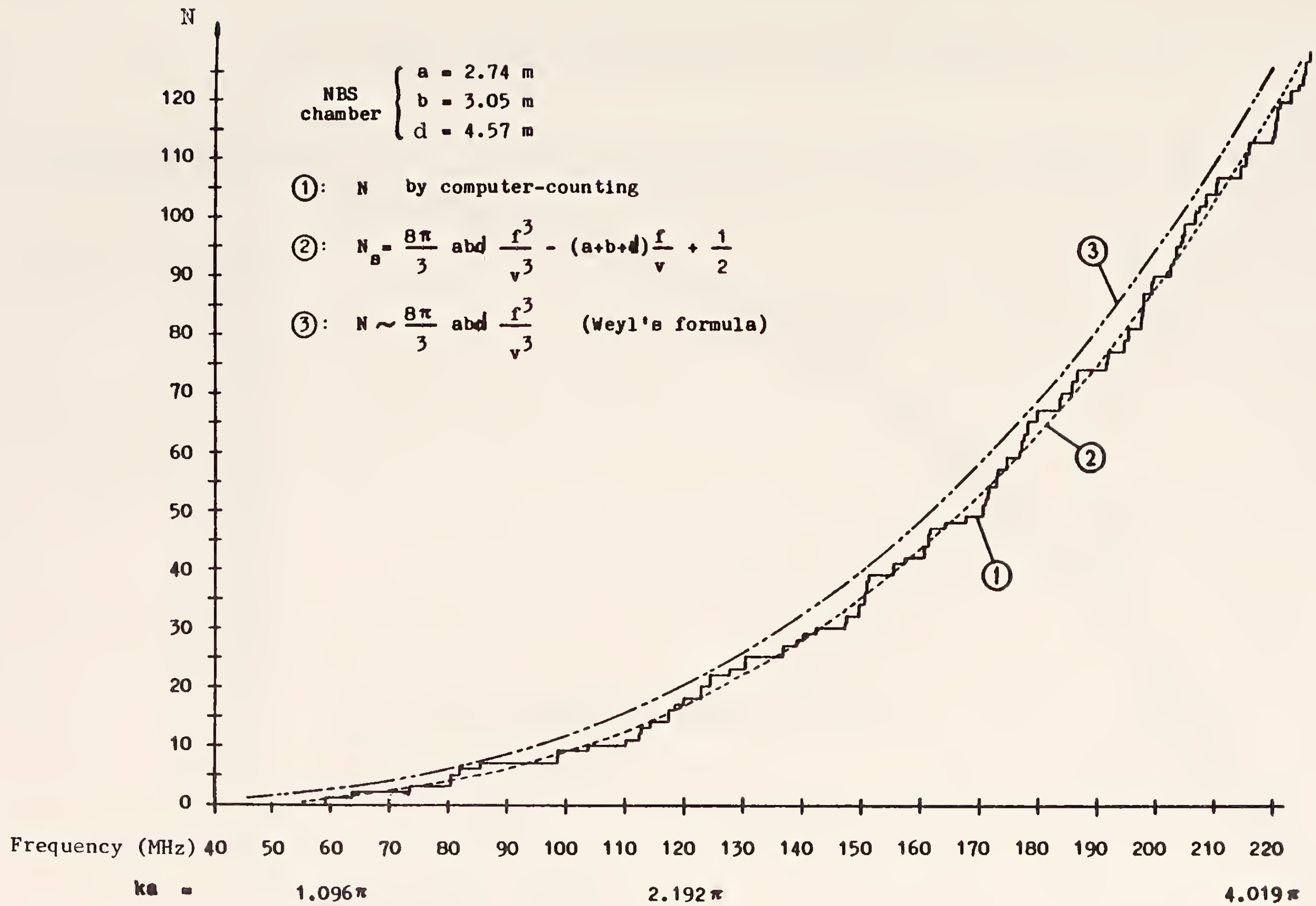


Figure 2.2 Total number of modes as a function of operating frequency for the NBS chamber.

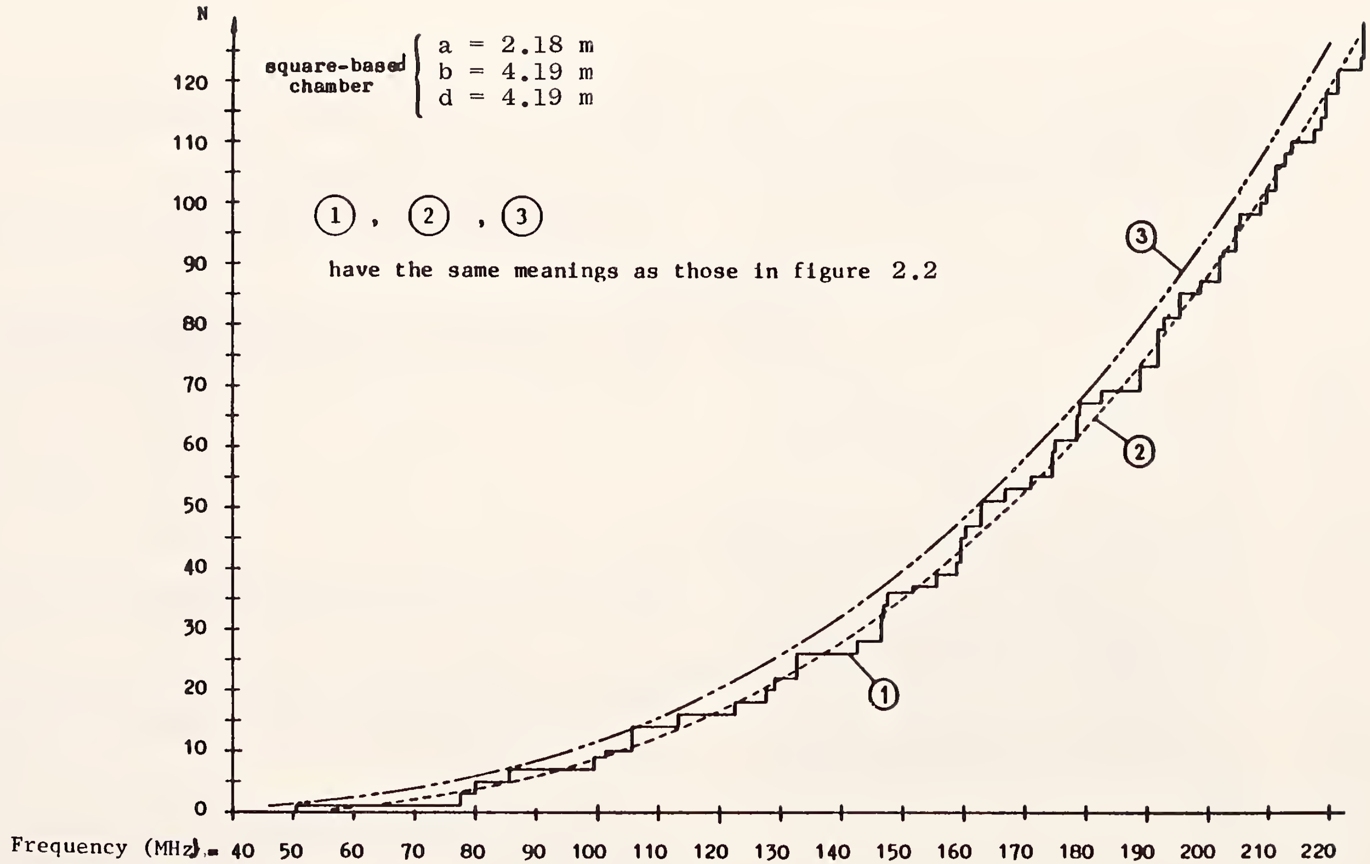


Figure 2.3 Total number of modes as a function of operating frequency for a square based chamber whose volume is the same as that of NBS chamber.

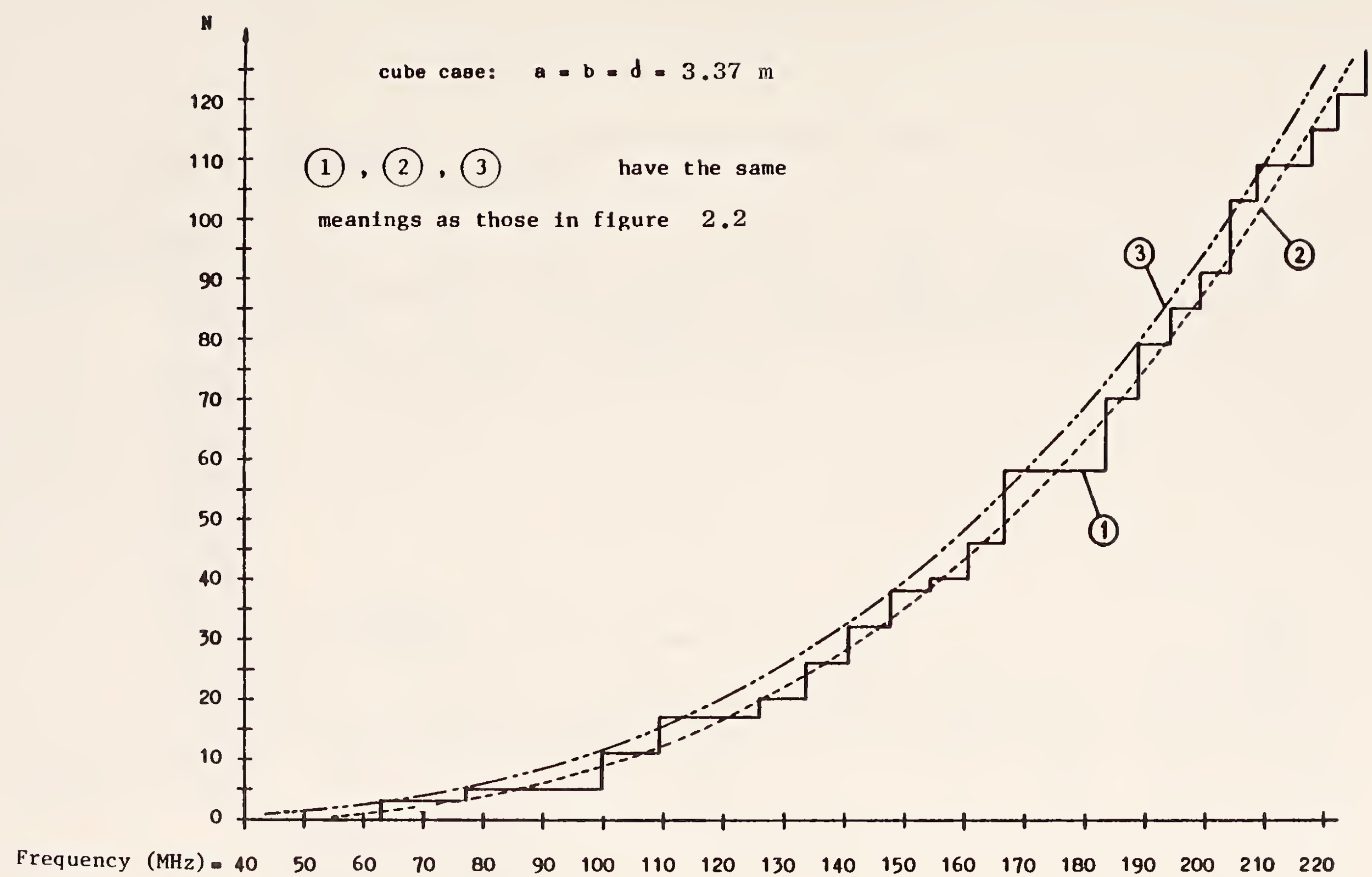


Figure 2.4 Total number of modes as a function of operating frequency for a cubic chamber whose volume is the same as that of NBS chamber.

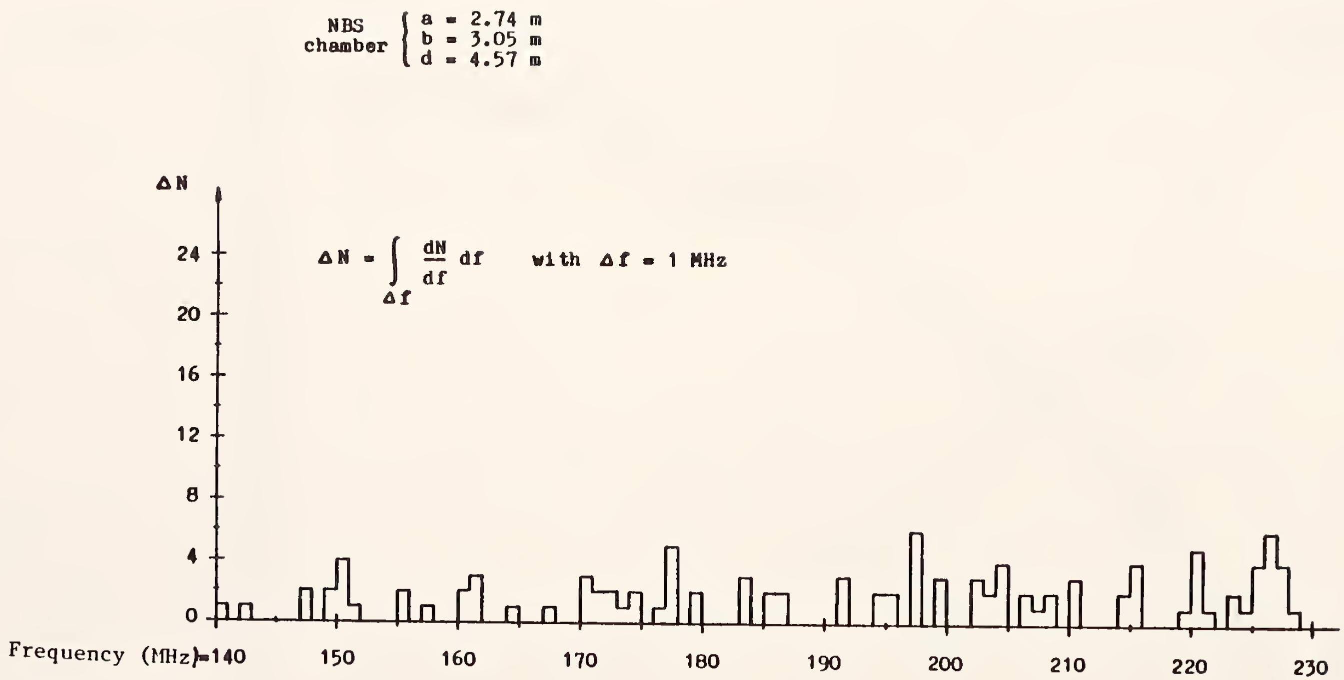


Figure 2.5 An illustration of mode degeneracy (NBS chamber).

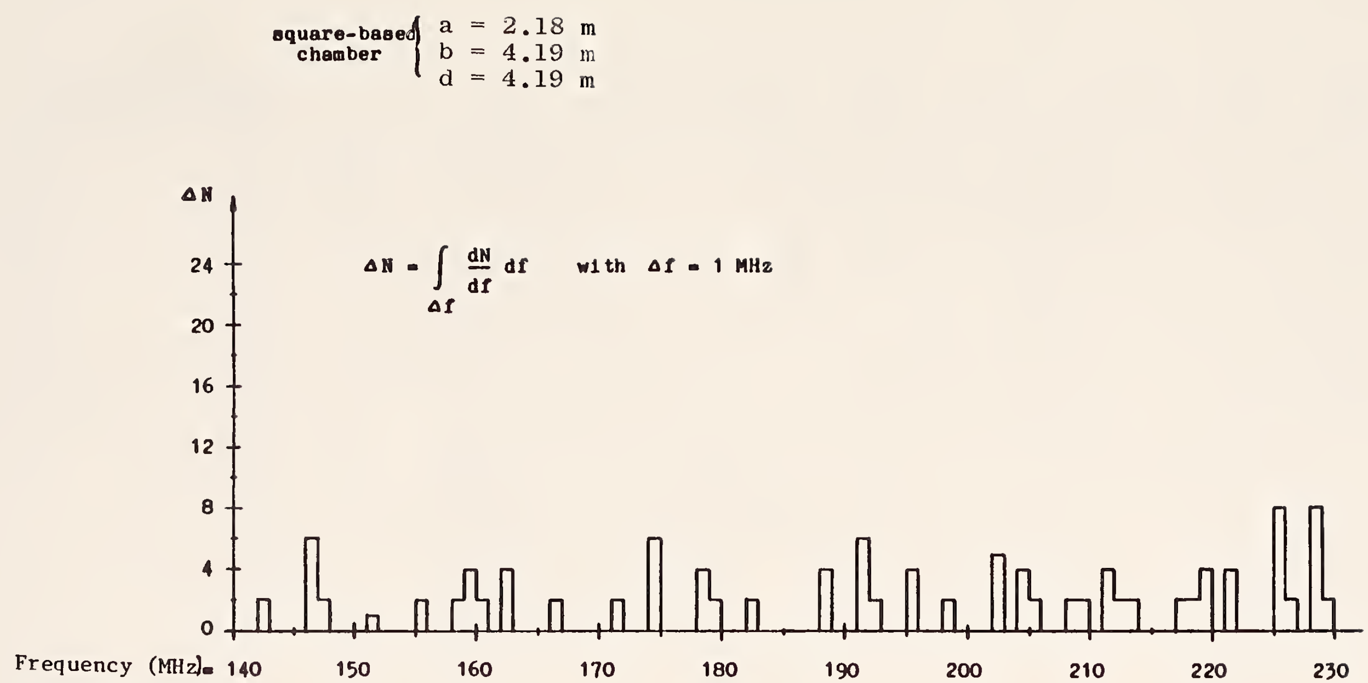


Figure 2.6 An illustration of mode degeneracy (square-base chamber).

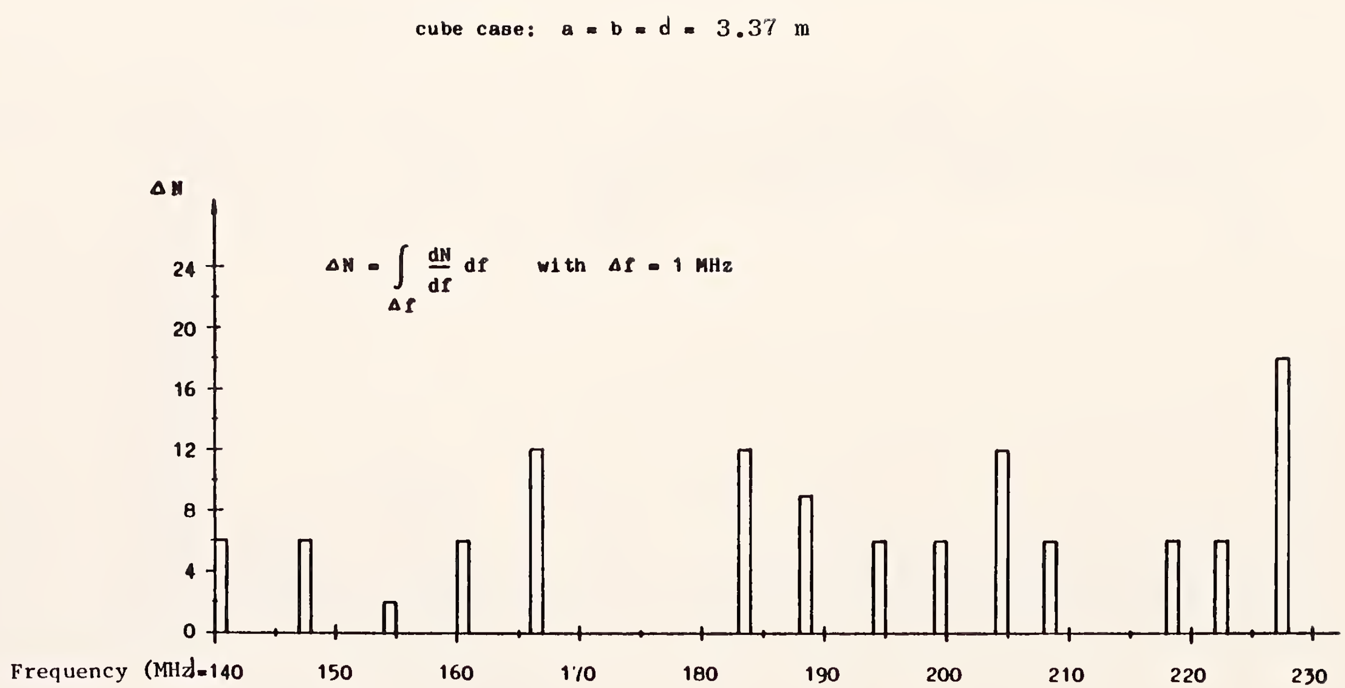


Figure 2.7 An illustration of mode degeneracy (cubic chamber).

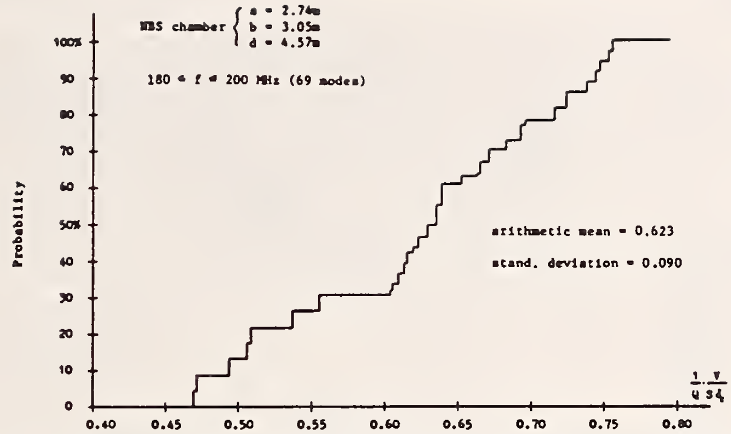


Figure 2.8 Cumulative distribution curve of the normalized 1/Q values in the 180 MHz to 200 MHz frequency band for the NBS chamber.

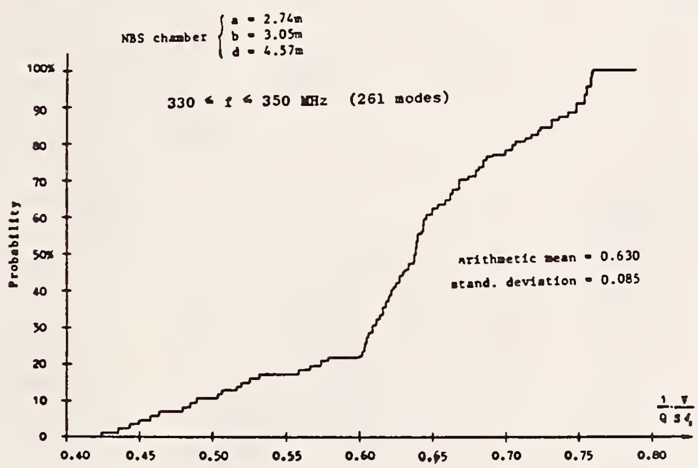


Figure 2.9 Cumulative distribution curve of the normalized 1/Q values in the 330 MHz to 350 MHz frequency band for the NBS chamber.

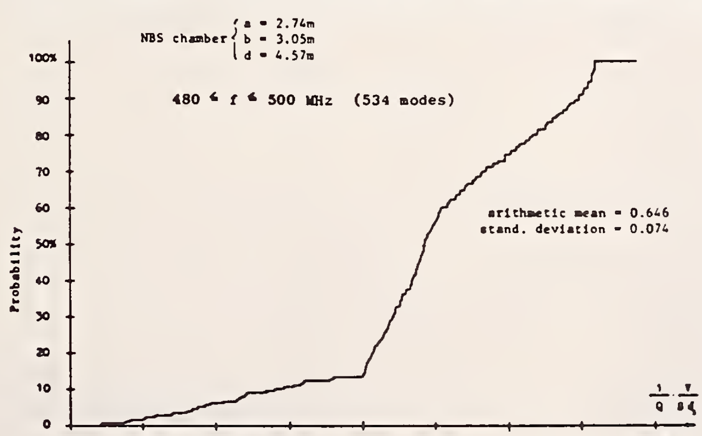


Figure 2.10 Cumulative distribution curve of the normalized 1/Q values in the 480 MHz to 500 MHz frequency band for the NBS chamber.

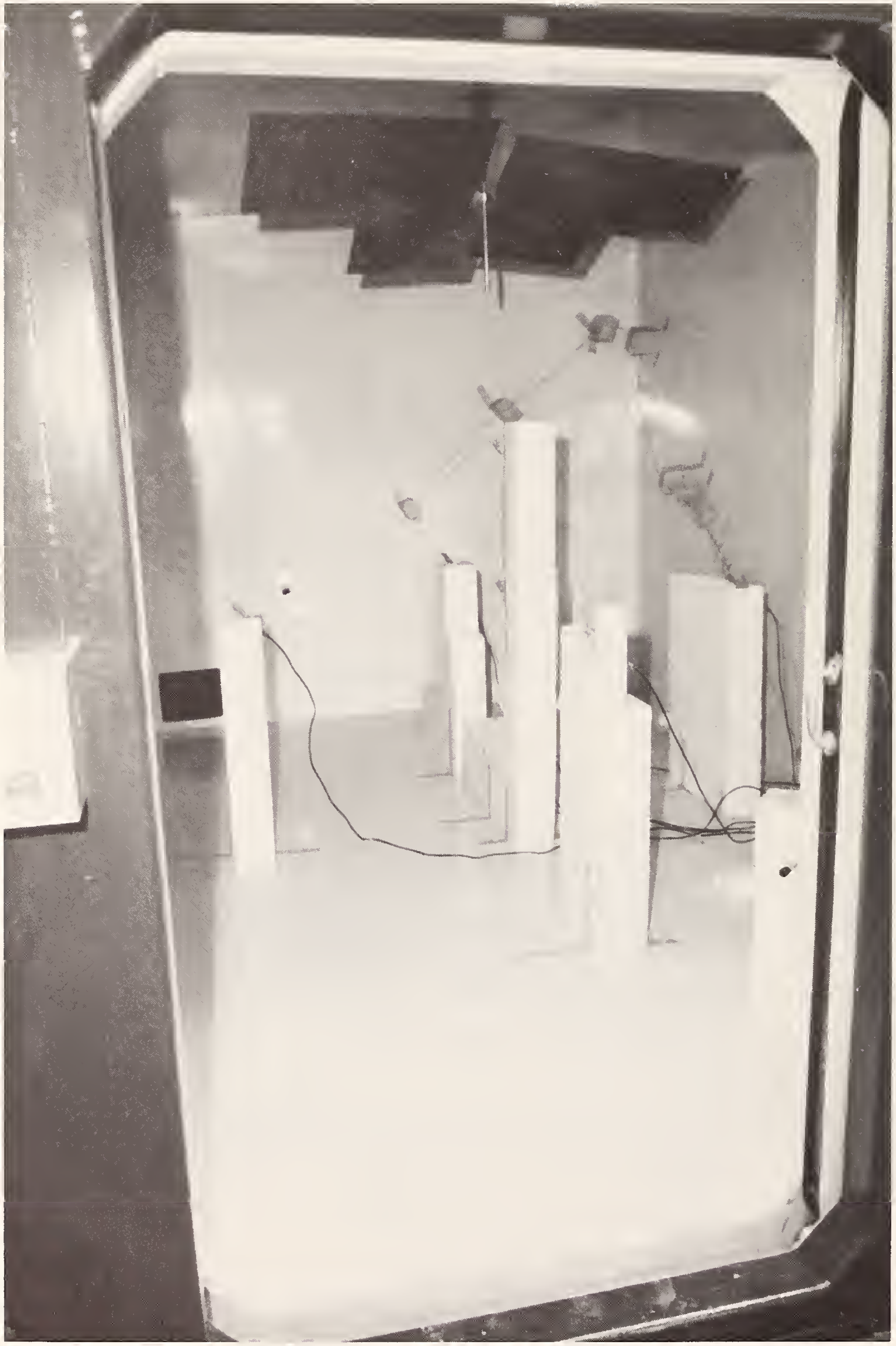


Figure 2.11 Photograph of interior of NBS reverberation chamber.

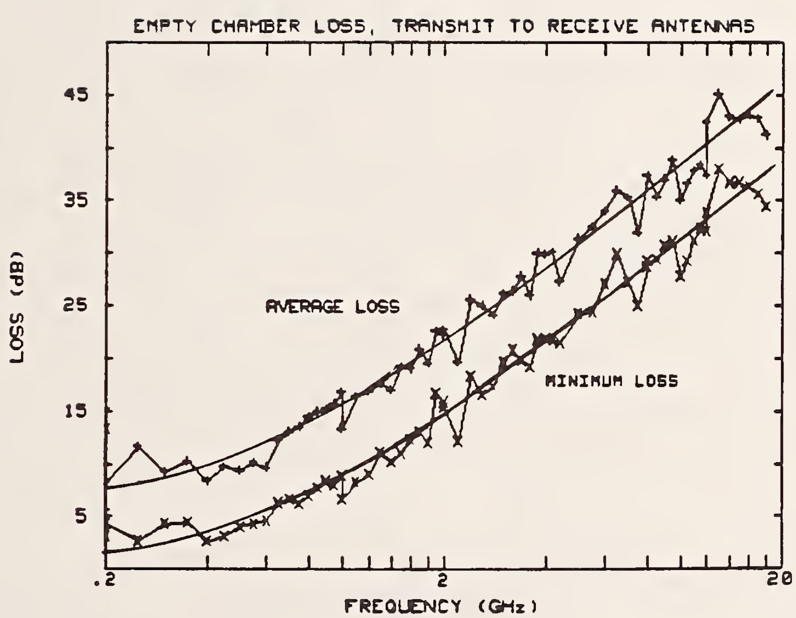


Figure 2.12 Average and minimum losses between transmitted and received powers measured at antennas' terminals inside NBS reverberation chamber. Transmitting antennas are: log periodic (200 MHz - 1000 MHz), ridged horn (1.0 GHz - 4.0 GHz), double ridged circular horn (4.0 GHz - 18 GHz). Receiving antennas are: long wire (200 MHz - 1000 MHz), ridged horn (1.0 GHz - 4.0 GHz), double ridged circular horn (4.0 GHz - 18 GHz).

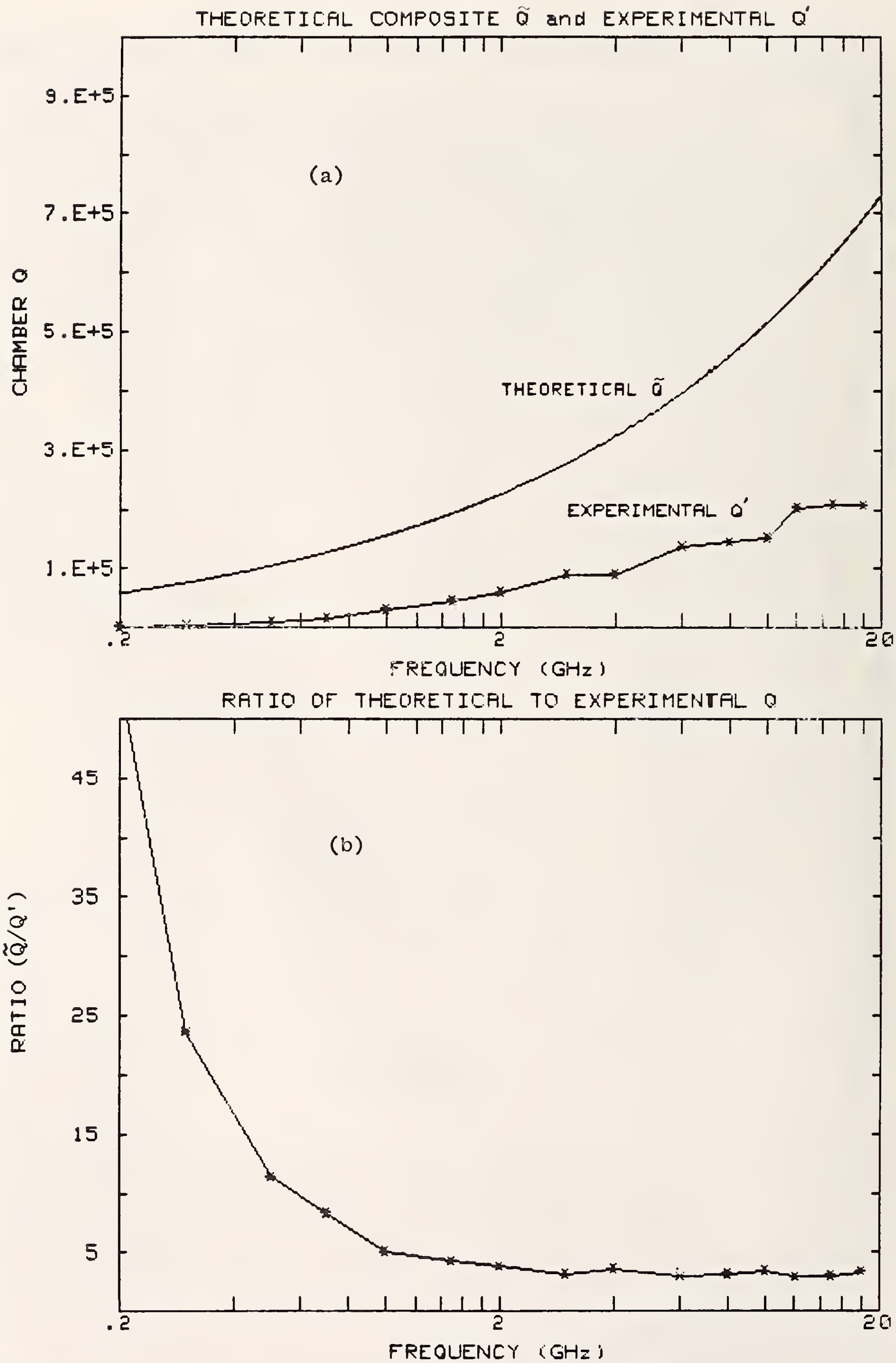


Figure 2.13 Theoretical composite $\tilde{Q}$ and experimental Q' determined for NBS reverberation chamber. a) Theoretical and experimental values of Q as a function of frequency. b) Ratio of the theoretical composite $\tilde{Q}$ to experimental Q' as a function of frequency.

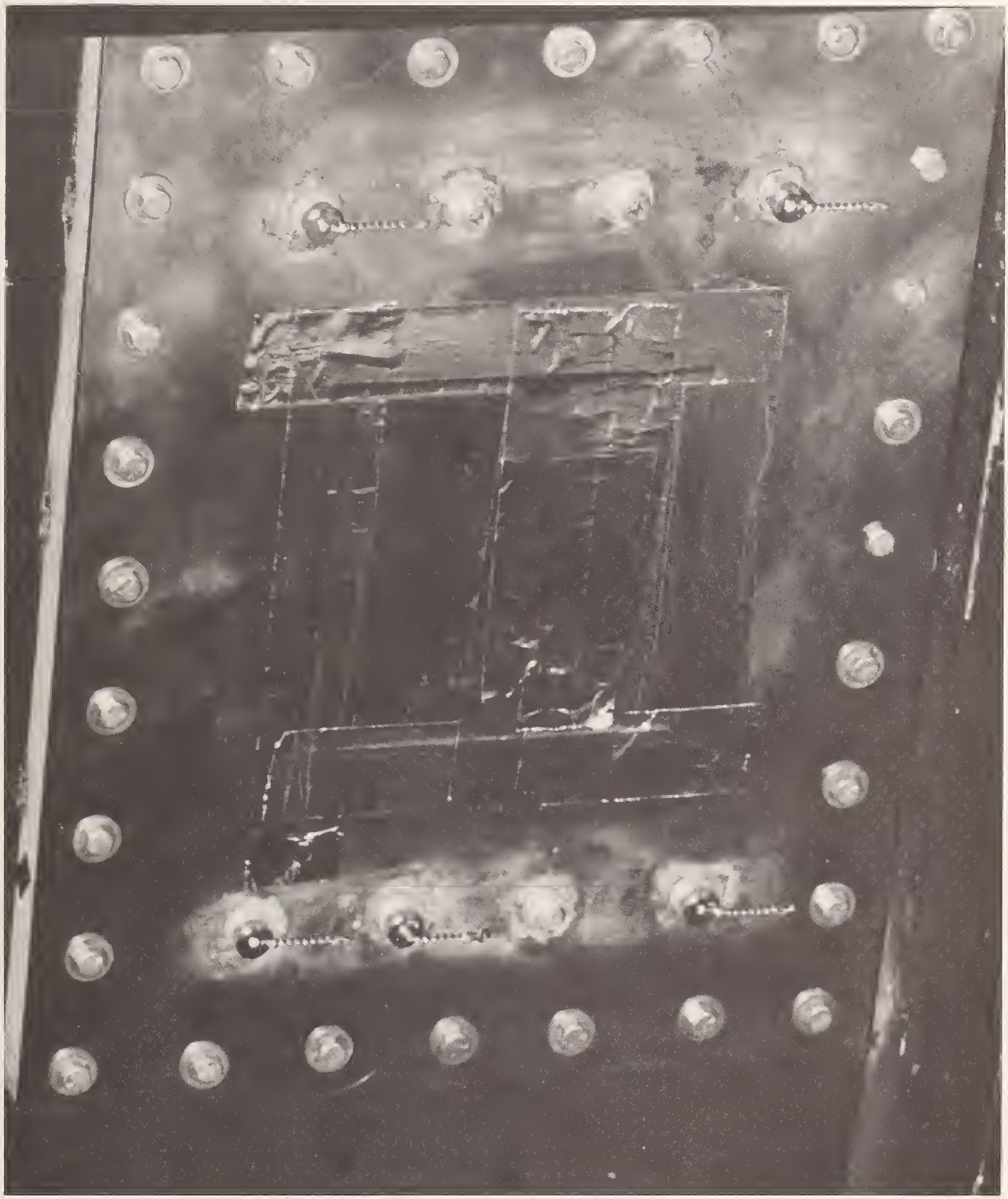


Figure 2.14 Bulkhead panel used for accessing NBS reverberation chamber.

Figure 2.15a Photograph of field tuner/stirrer installed in McDonnell Douglas Corporation 2.4 m x 3.0 m x 7.6 m TEMEC (reverberation chamber) facility.

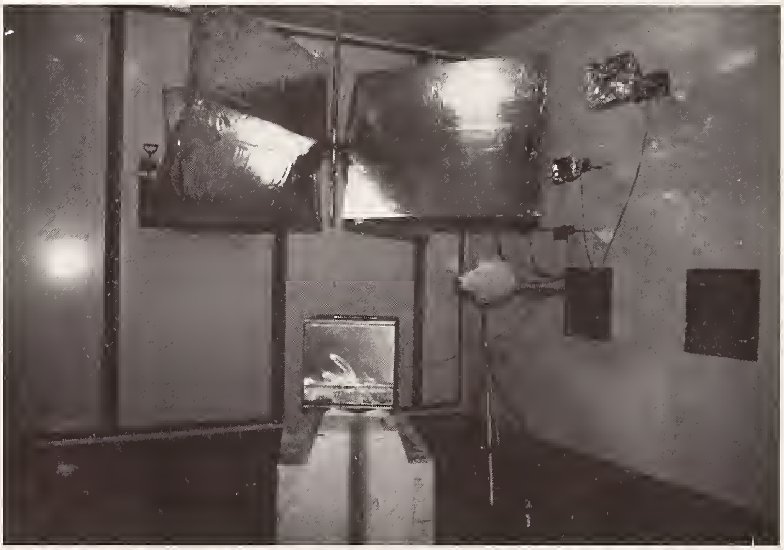


Figure 2.15b Photograph of field tuner/stirrer installed in NSWC 3.5 m x 5.2 m x 5.9 m reverberation chamber.

Figure 2.15c. Photograph of field tuner/stirrer installed in NBS 2.7 m x 3.1 m x 4.6 m reverberation chamber.

Figure 2.15. Tuner designs for use in reverberation chambers. a) McDonnell Douglas Corp. TEMEC tuner, b) NSWC chamber tuner, c) NBS chamber tuner.

Figure 2.16 Photograph of tuner, log-periodic transmitting antenna and NBS isotropic probes inside NBS reverberation chamber.

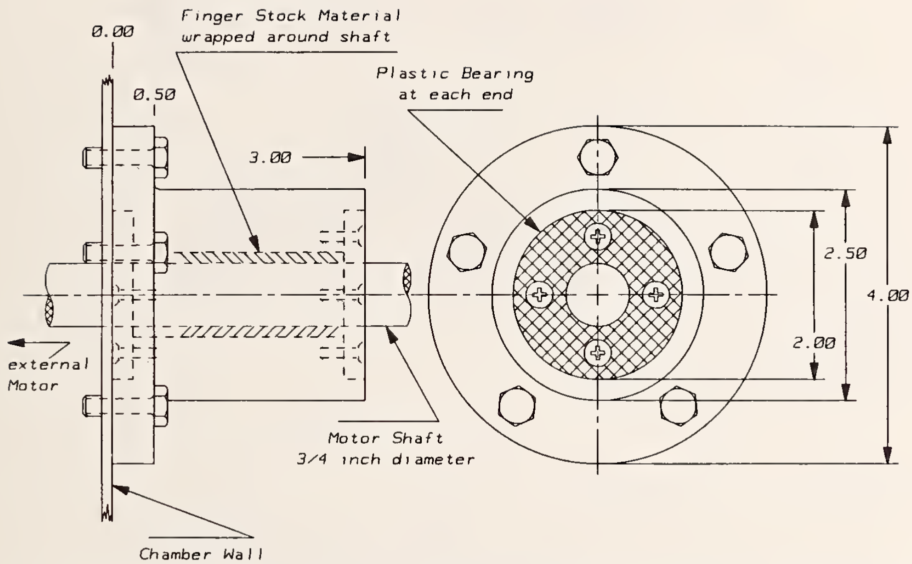
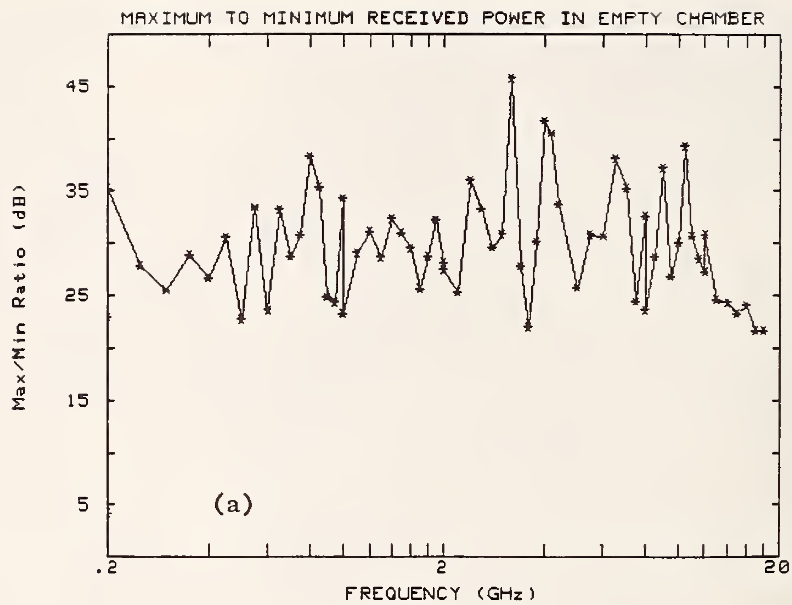


Figure 2.17a. Details of collet for mounting tuner shaft to motor through wall of reverberation chamber.

Figure 2.17b. Photograph of tuner shaft mounted through collet on ceiling of NBS reverberation chamber.

Figure 2.17 Details of tuner and stepping motor mounting for the NBS reverberation chamber.



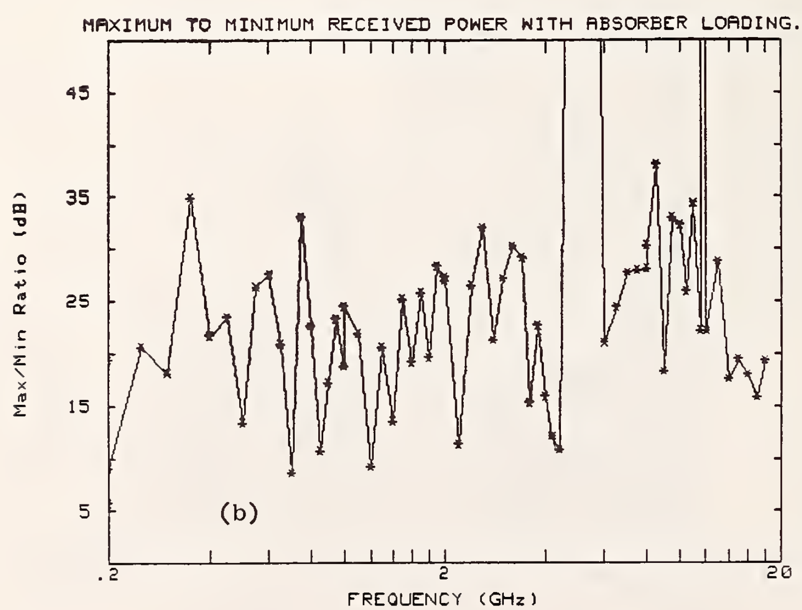


Figure 2.18 Ratio of maximum to minimum received power obtained by rotating tuner in the frequency range 200 MHz to 18 GHz. a) Empty chamber, b) Four pieces of 66 cm rf absorber placed upright in center of chamber, 0.5 m above floor.

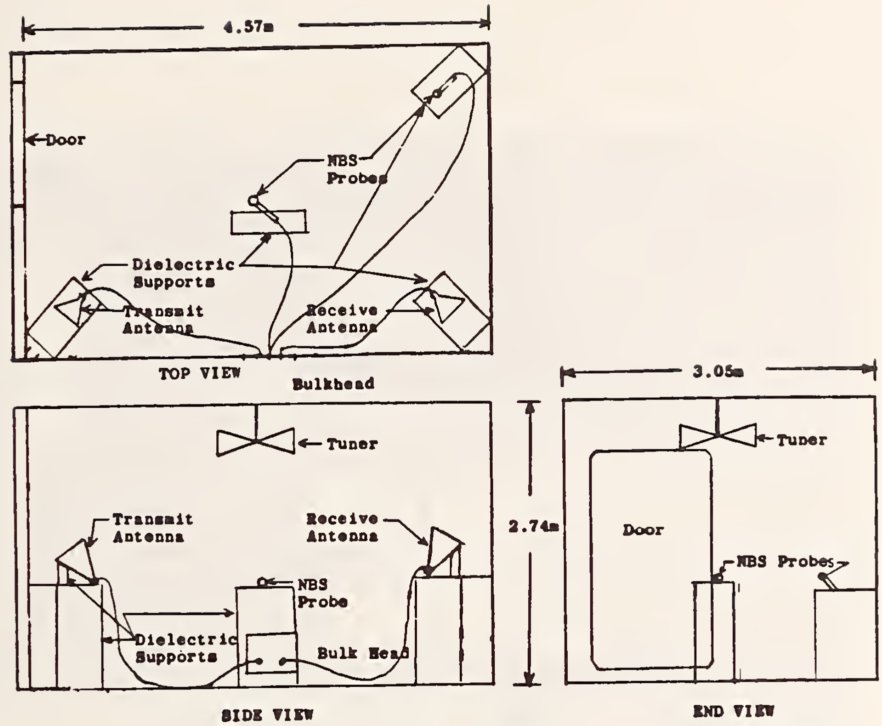


Figure 2.19a. Cross sectional views of NBS reverberation chamber for use at frequencies above 1.0 GHz showing location of antenna and NBS probes.

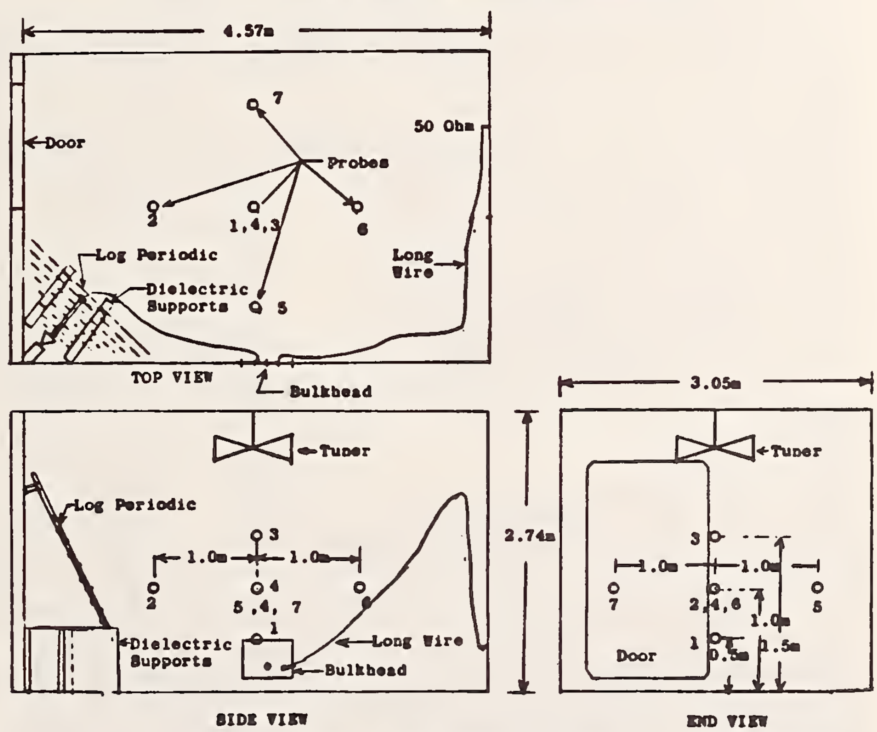


Figure 2.19b. Cross sectional views of NBS reverberation chamber for use at frequencies below 1.0 GHz showing location of antenna and array of NBS probes.

Figure 2.19 Cross sectional views of NBS reverberation chamber showing placement of tuner, transmitting and receiving antennas, and NBS probes.

x (cm)	h(x) (cm)
0	0.05
15.0	0.13
30.0	0.17
45.0	0.25
60.0	0.36
75.0	0.58
90.0	1.02
105.0	1.98
120.0	4.41
135.0	11.55
150.0	20.00

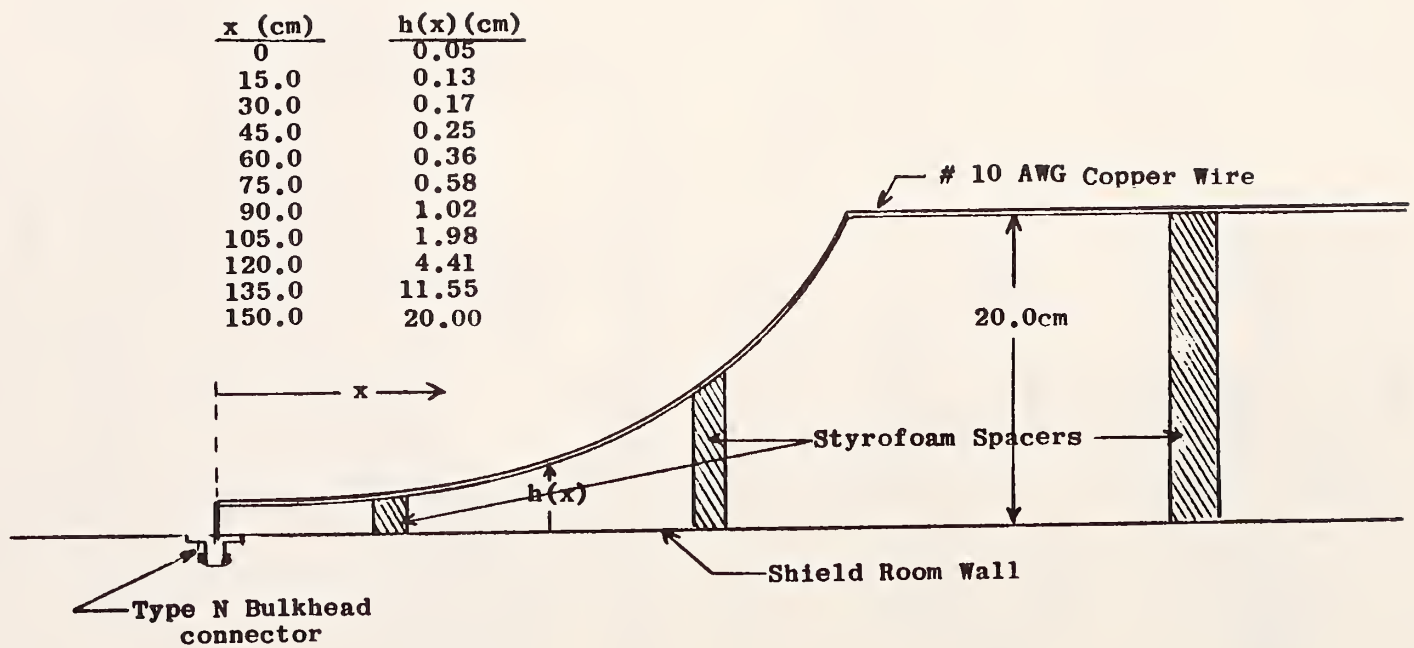


Figure 2.20 Design of taper section of long wire antenna for use in Reverberation chamber.

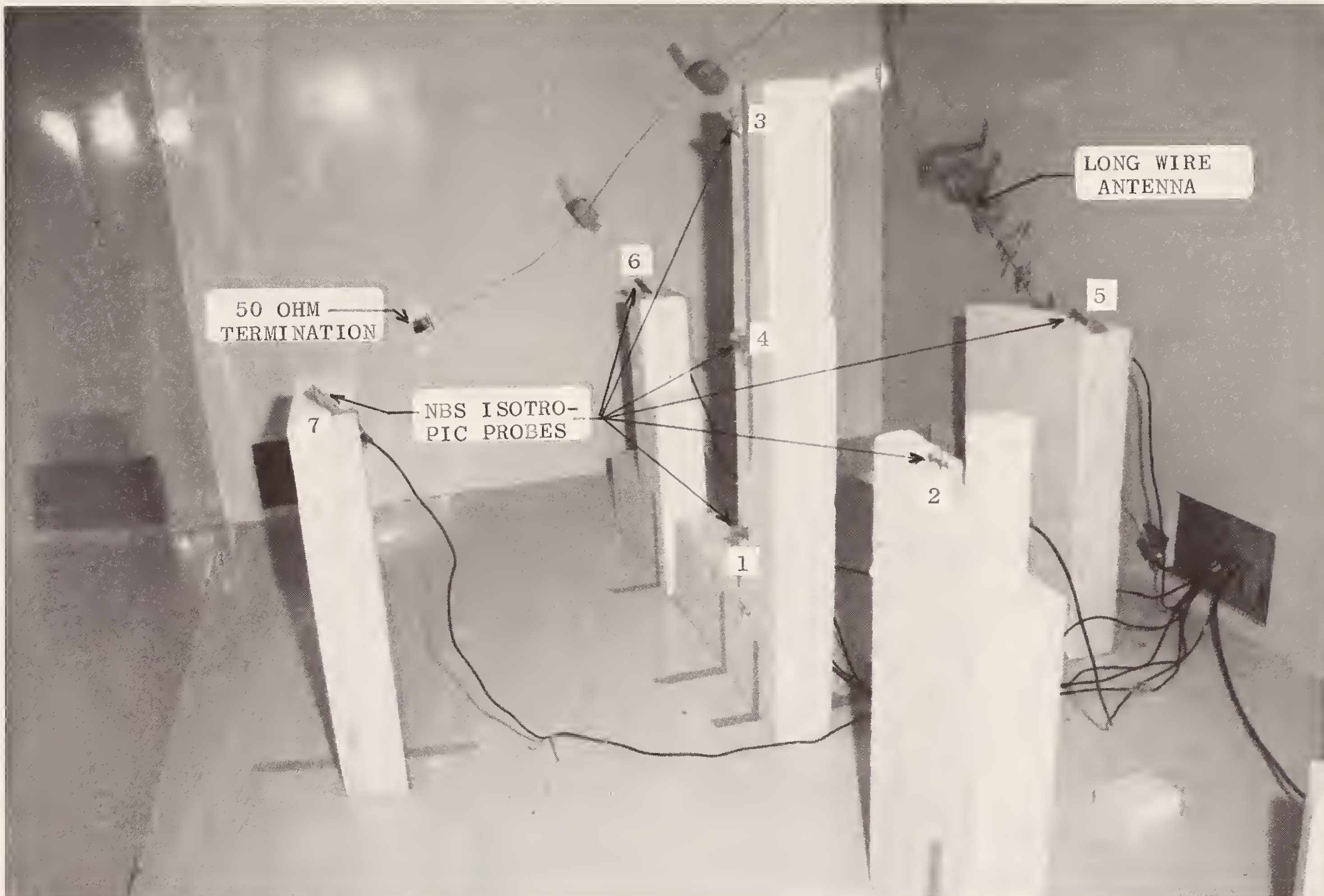


Figure 2.21 Photograph showing long wire antenna and NBS probes placement inside NBS reverberation chamber.

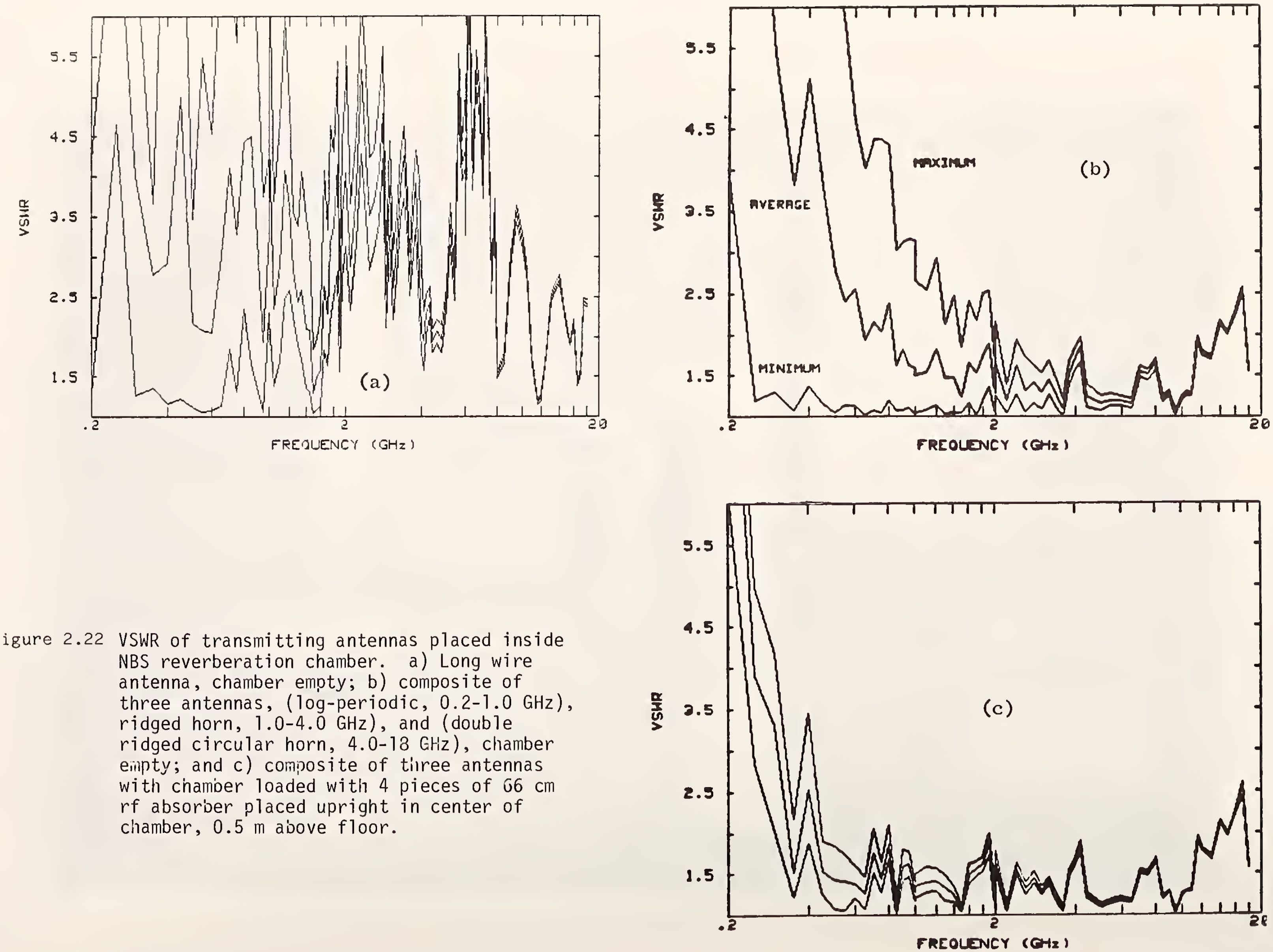


Figure 2.22 VSWR of transmitting antennas placed inside NBS reverberation chamber. a) Long wire antenna, chamber empty; b) composite of three antennas, (log-periodic, 0.2-1.0 GHz), ridged horn, 1.0-4.0 GHz), and (double ridged circular horn, 4.0-18 GHz), chamber empty; and c) composite of three antennas with chamber loaded with 4 pieces of 66 cm rf absorber placed upright in center of chamber, 0.5 m above floor.

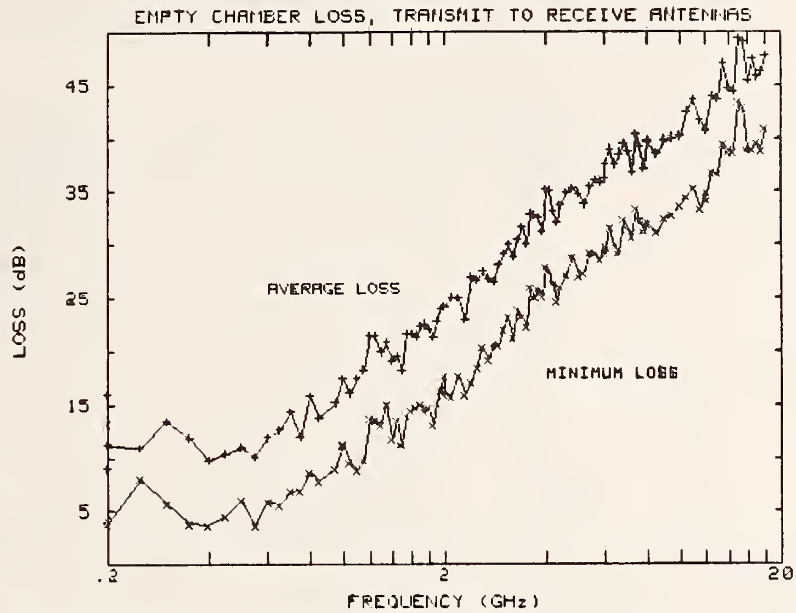


Figure 2.23 Average and minimum losses between transmitted and received powers measured at antennas's terminals inside NBS reverberation chamber. Long wire antenna transmitting (200 MHz - 18 GHz), composite of three antenna receiving (log periodic 200 MHz - 1000 MHz, ridged horn, 1.0 GHz - 4.0 GHz, double ridged circular horn, 4.0 GHz - 18 GHz).

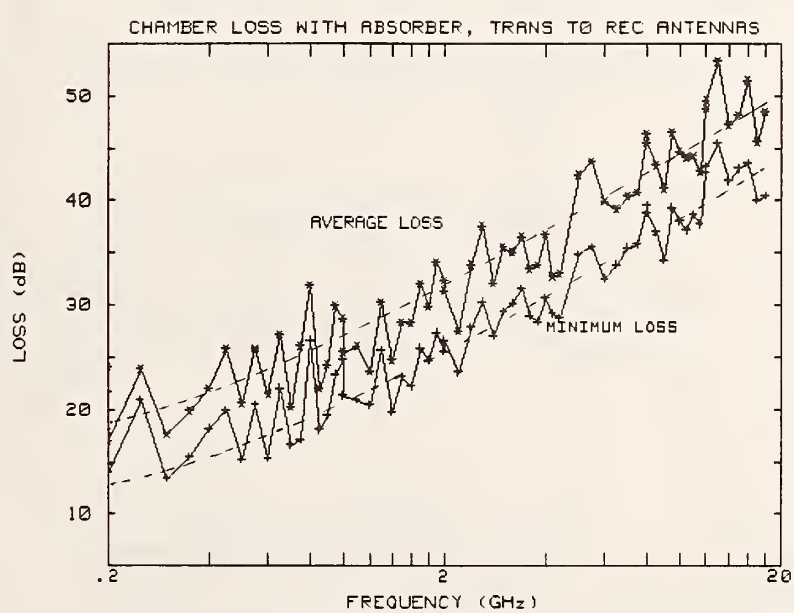


Figure 2.24 Average and minimum losses between transmitted and received powers measured at antennas' terminals inside NBS chamber with four pieces of 66 cm rf absorber upright in center of chamber, 0.5 m above floor. Composite of three antennas used for transmitting and receiving.

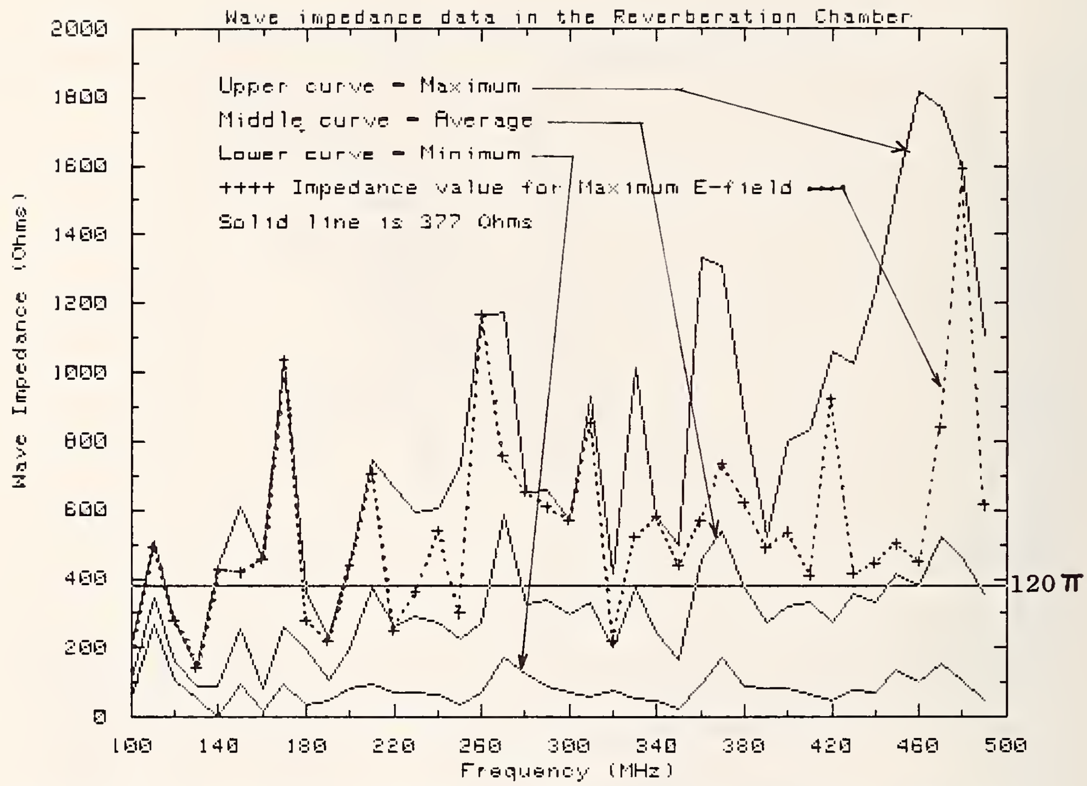


Figure 2.25 Magnitude of wave impedance inside NBS reverberation chamber.

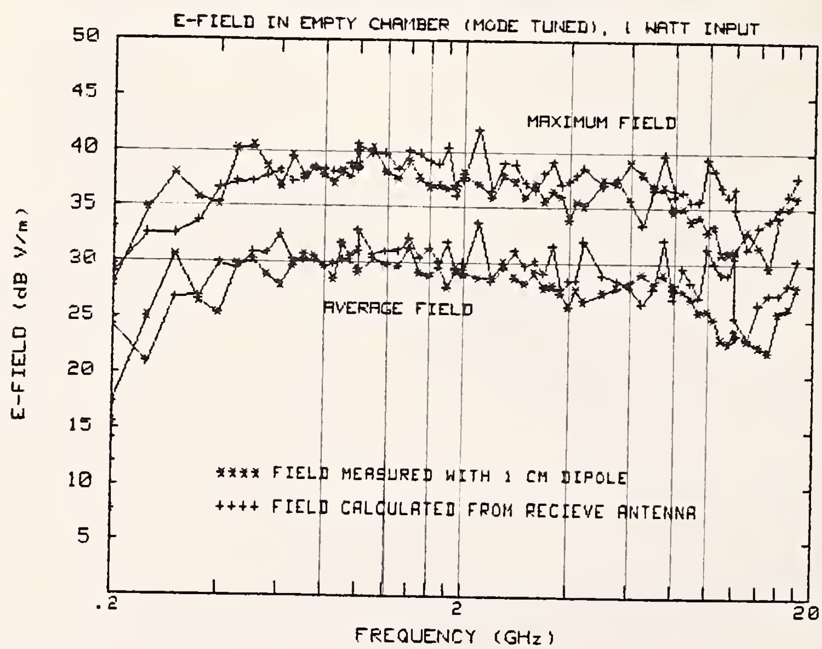
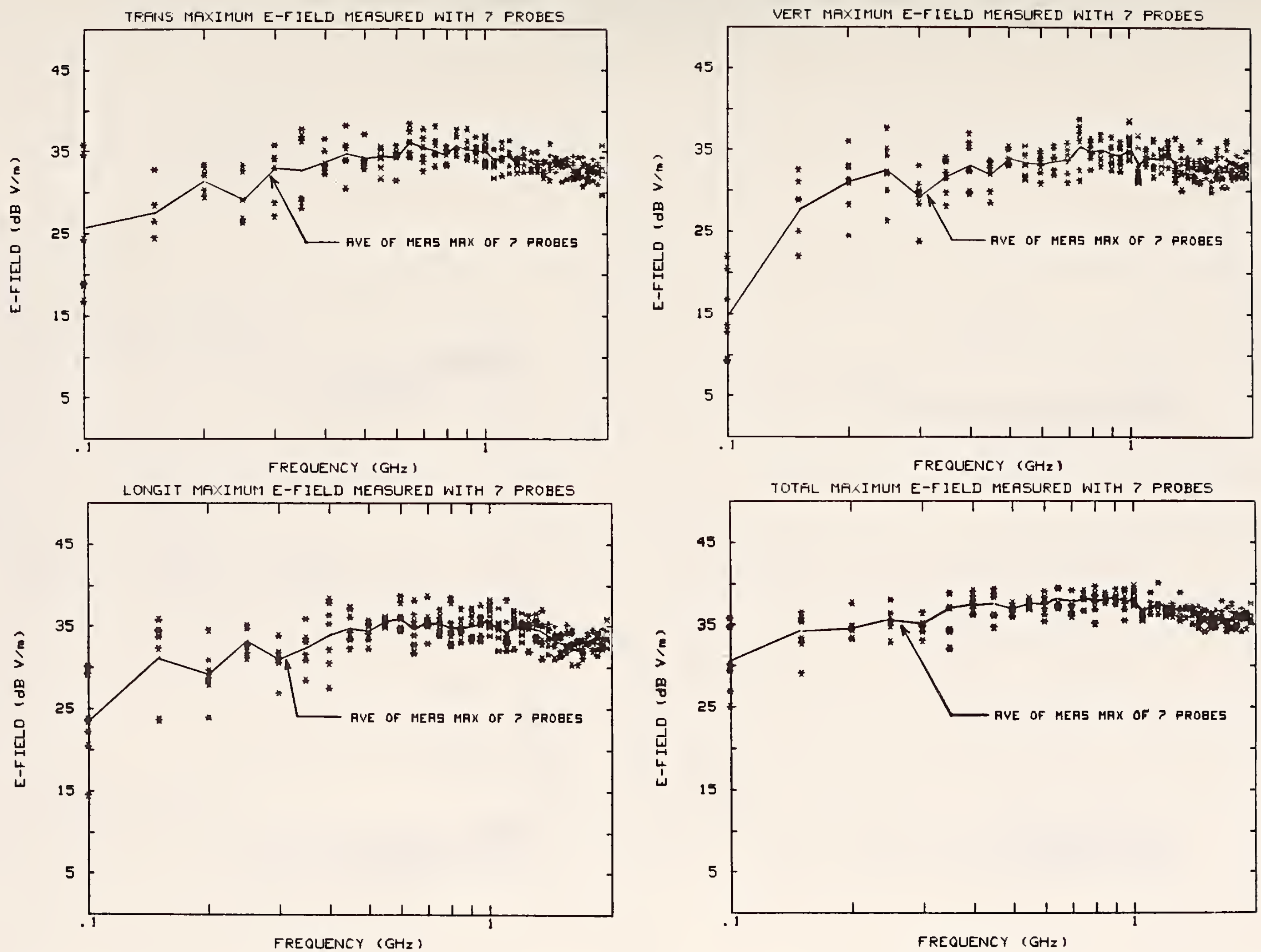
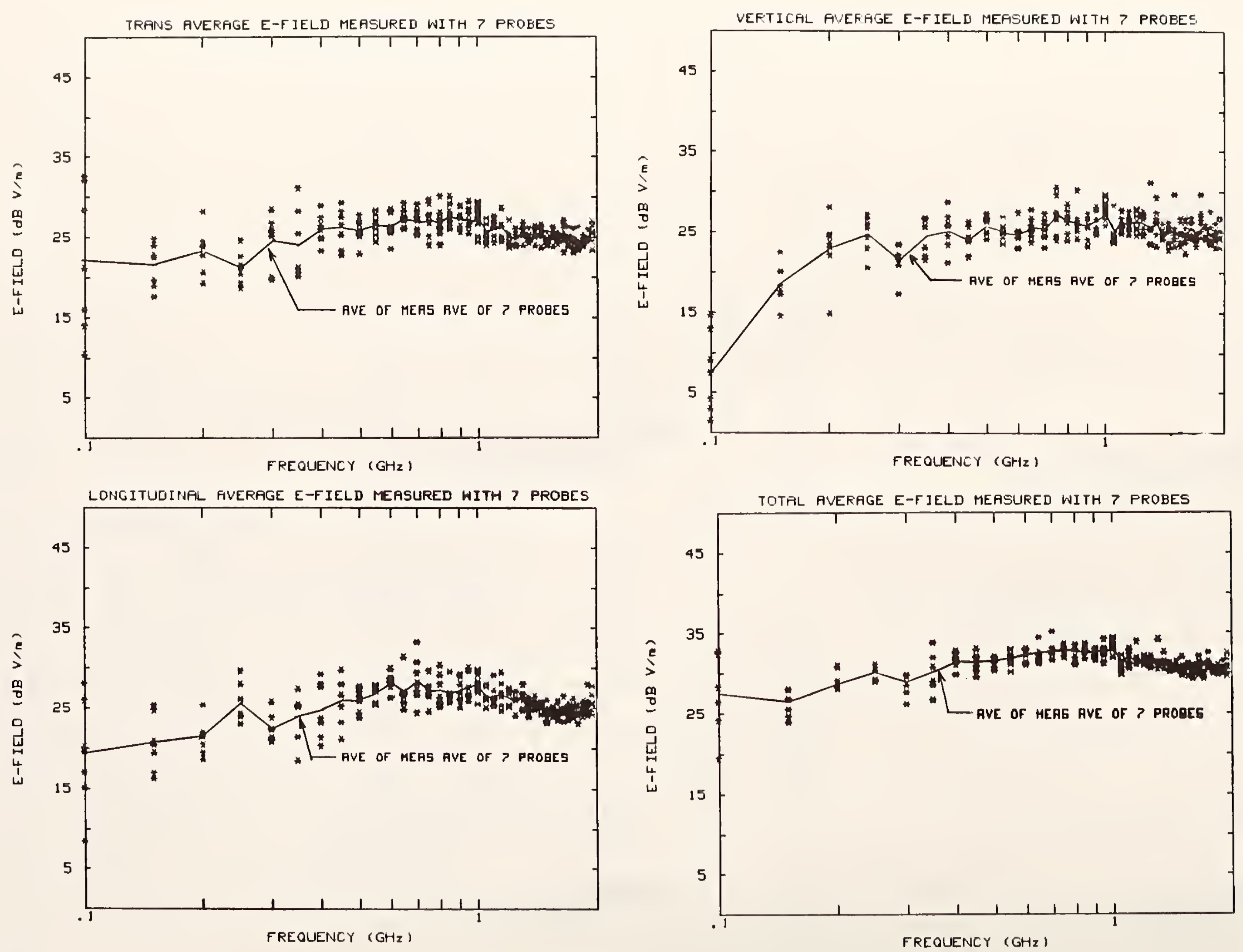


Figure 2.26 Average and maximum E-field strengths inside empty NBS reverberation chamber for 1 W net input power determined from: a) composite of 3 antennas received power measurements, and b) calibrated 1 cm dipole probe measurements.

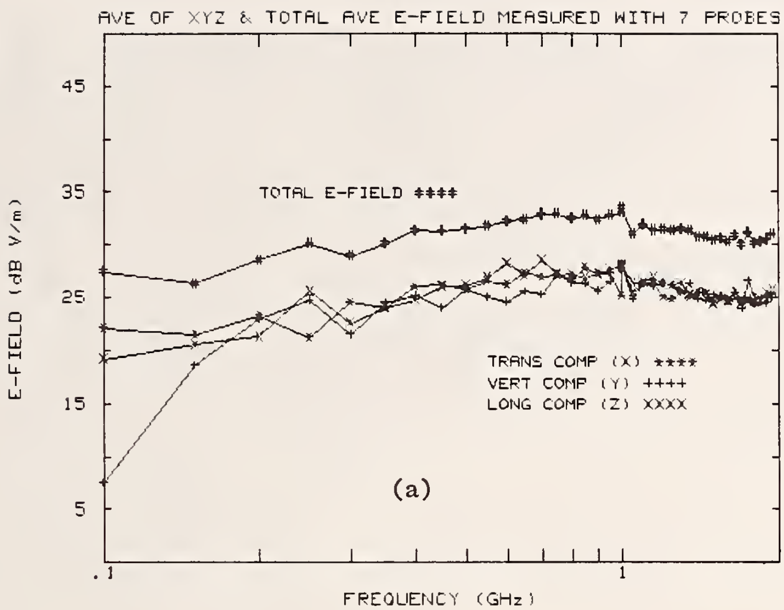

TRANS MAXIMUM E-FIELD MEASURED WITH 7 PROBES
VERT MAXIMUM E-FIELD MEASURED WITH 7 PROBES
LONGIT MAXIMUM E-FIELD MEASURED WITH 7 PROBES
TOTAL MAXIMUM E-FIELD MEASURED WITH 7 PROBES
E-FIELD (dB V/m)
FREQUENCY (GHz)
AVE OF MEAS MAX OF 7 PROBES
45
35
25
15
5
.1
1

(a)



(b)

Figure 2.27 E-field strength measured inside NBS reverberation chamber using array of 7 NBS isotropic probes: (a) maximum, and (b) average. Net power normalized to 1 Watt. Transmitting antennas are: log periodic (100 MHz - 1 GHz), ridged horn (1 GHz - 2 GHz).



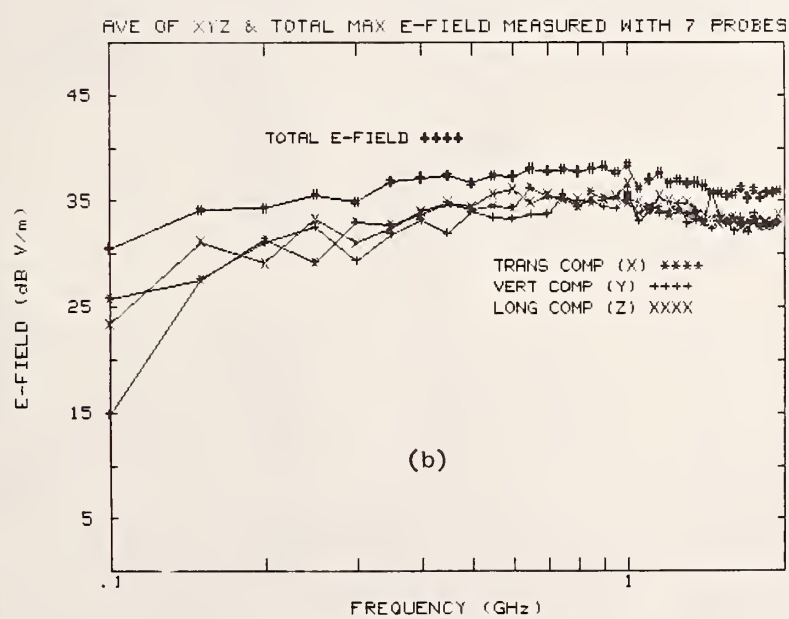


Figure 2.28 Mean values of the E-field strength measured inside NBS reverberation chamber using array of 7 NBS isotropic probes with 1 W net input power: (a) average, and (b) maximum. Data determined from maximum and average values of the 7 probes (7 locations) for the three orthogonal components and their sum (total) using 200 tuner positions (1.8 degree increments).

Figure 3.1a Photograph showing 30 cm x 50 cm x 60 cm welded aluminum box inside NBS reverberation chamber.

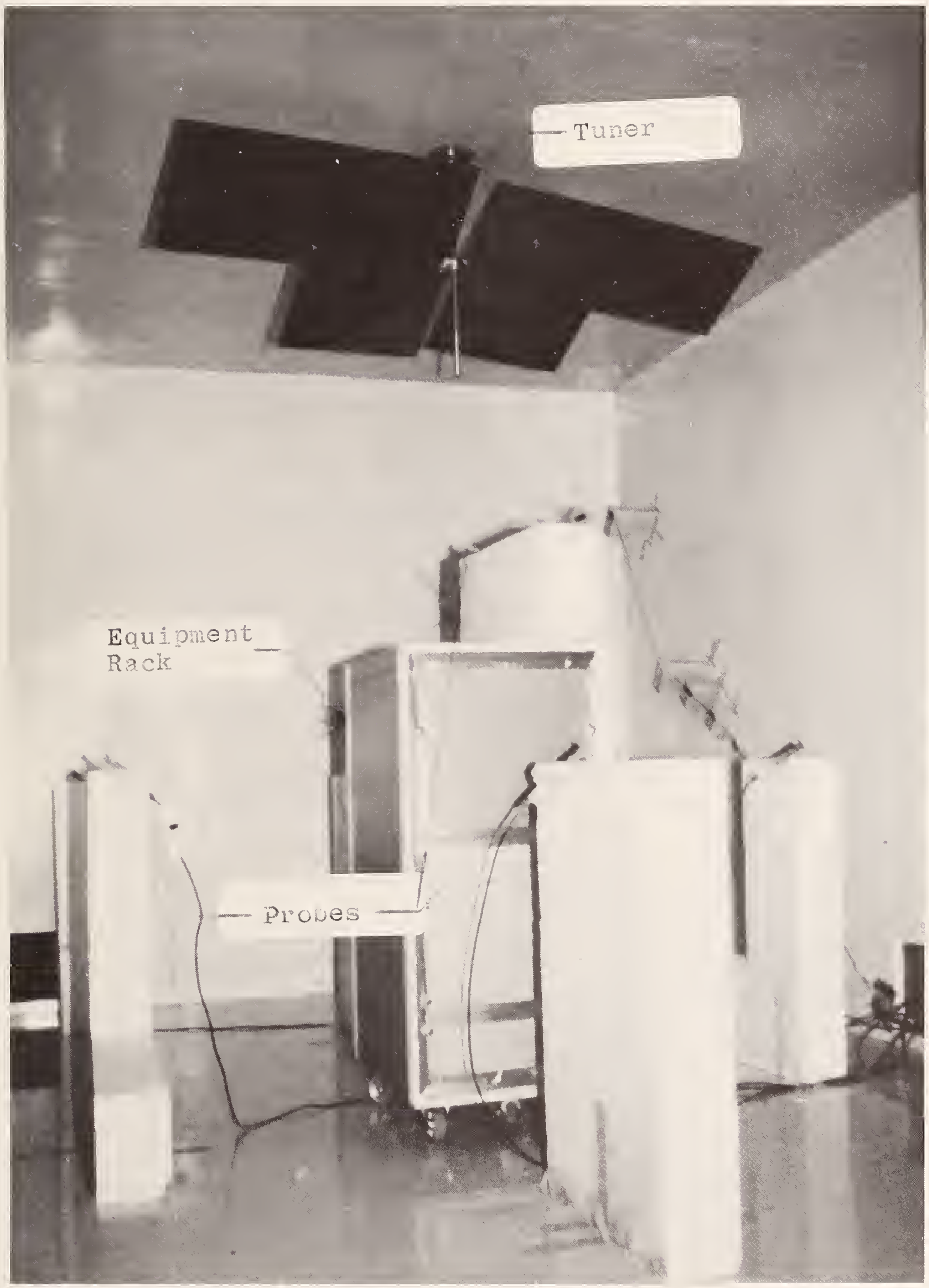
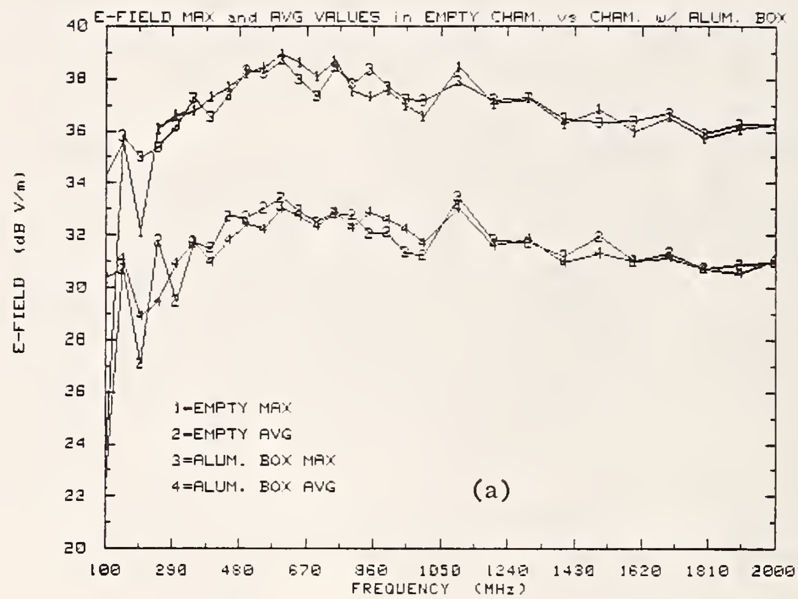


Figure 3.1b Photograph showing rolling equipment rack inside NBS reverberation chamber.

Figure 3.1 Placement of metallic objects inside NBS reverberation chamber to evaluate scattering effects upon E-field spatial distribution. a) Photograph showing 30 cm x 50 cm x 60 cm welded aluminum box inside NBS reverberation chamber. b) Photograph showing rolling equipment rack inside NBS reverberation chamber.



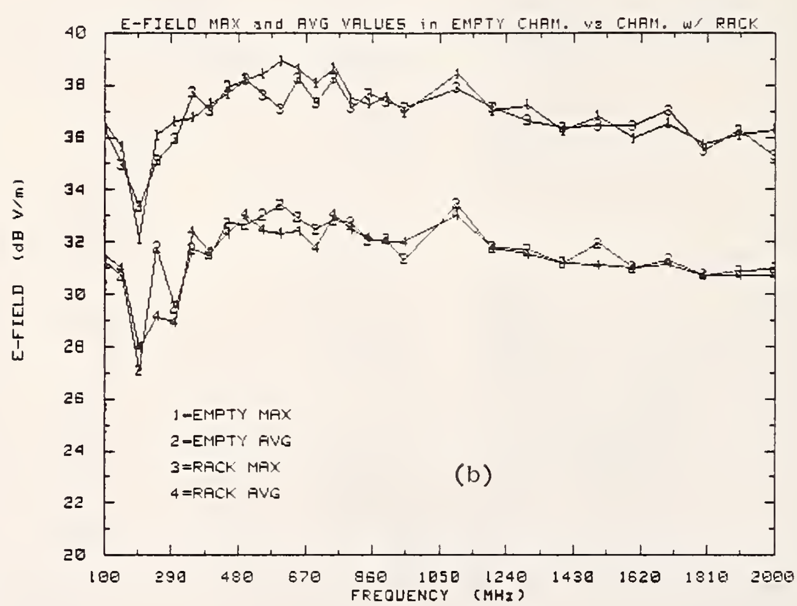


Figure 3.2 Comparison of the mean value of the average and maximum E-field strength measured using array of probes placed inside NBS reverberation chamber with chamber empty or with scattering object placed at center of test zone. a) 30 cm x 50 cm x 60 cm aluminum box, b) Rolling equipment rack.

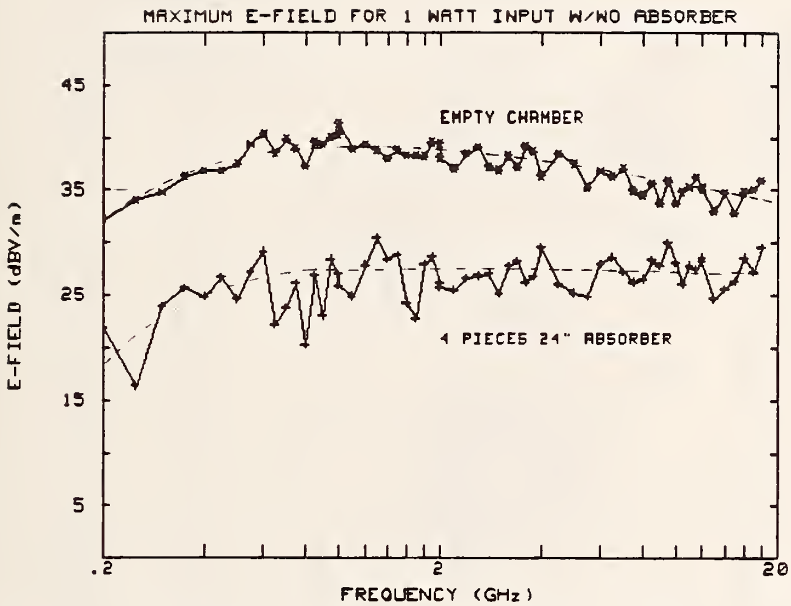


Figure 3.3 Maximum E-field strength inside empty chamber and chamber loaded with 4 pieces of 66 cm rf absorber for 1 W net input power determined from composite of 3 antennas received power measurements. Data obtained using mode stirring approach.

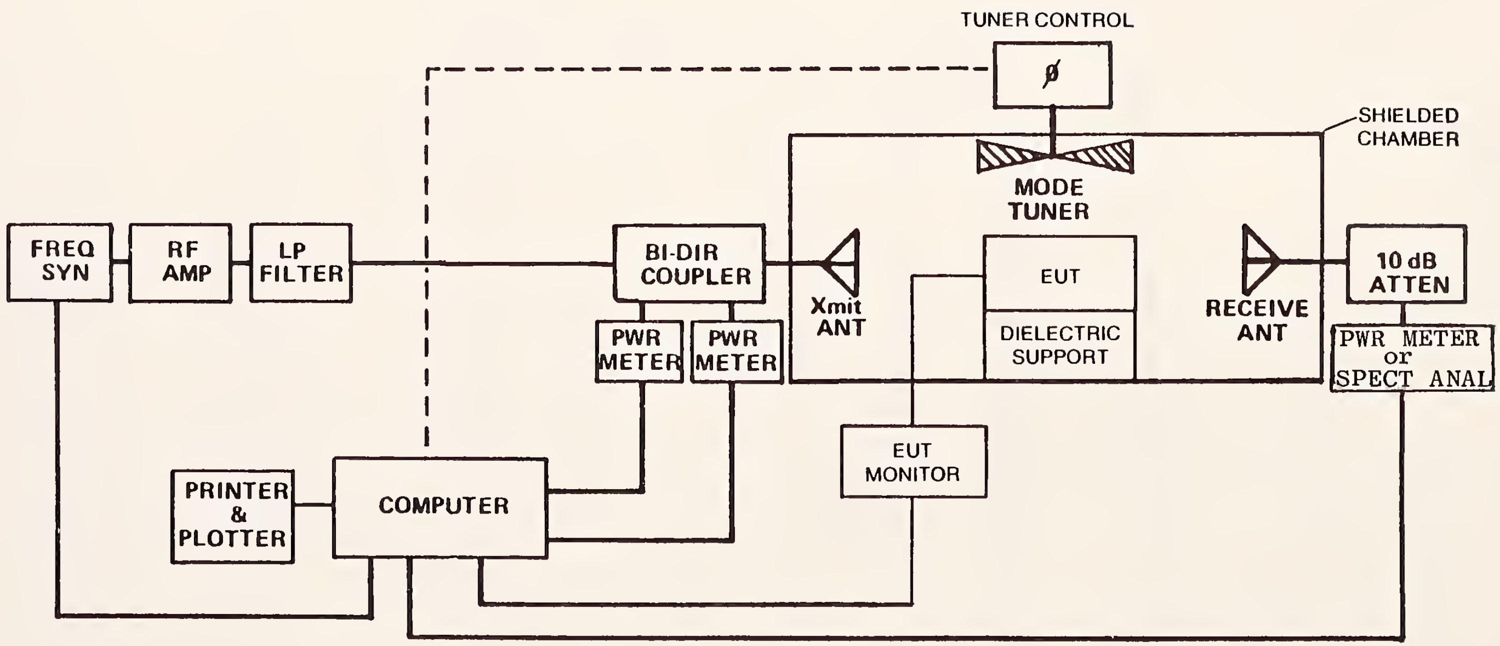


Figure 4.1 Block diagram of NBS reverberation chamber evaluation and EMC measurement system.

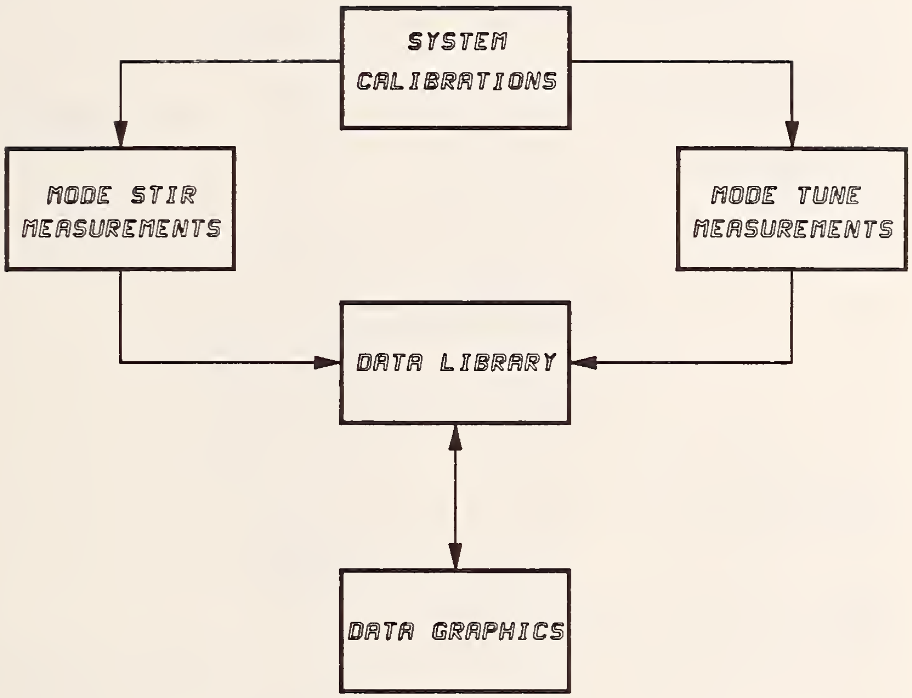


Figure 4.2 Major software tasks for performing and evaluation susceptibility tests using a reverberation chamber.

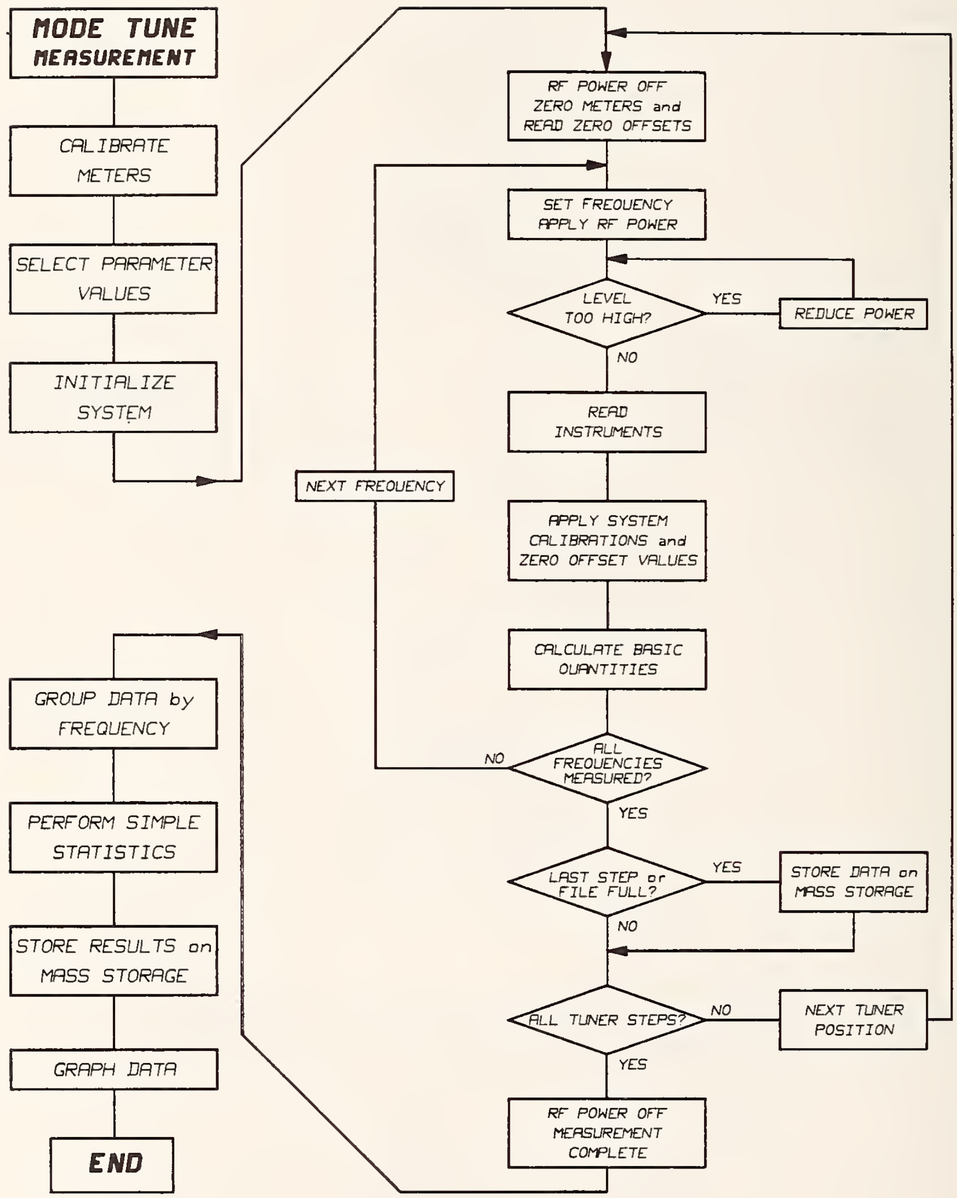


Figure 4.3   Flow diagram for mode-tuned measurements.

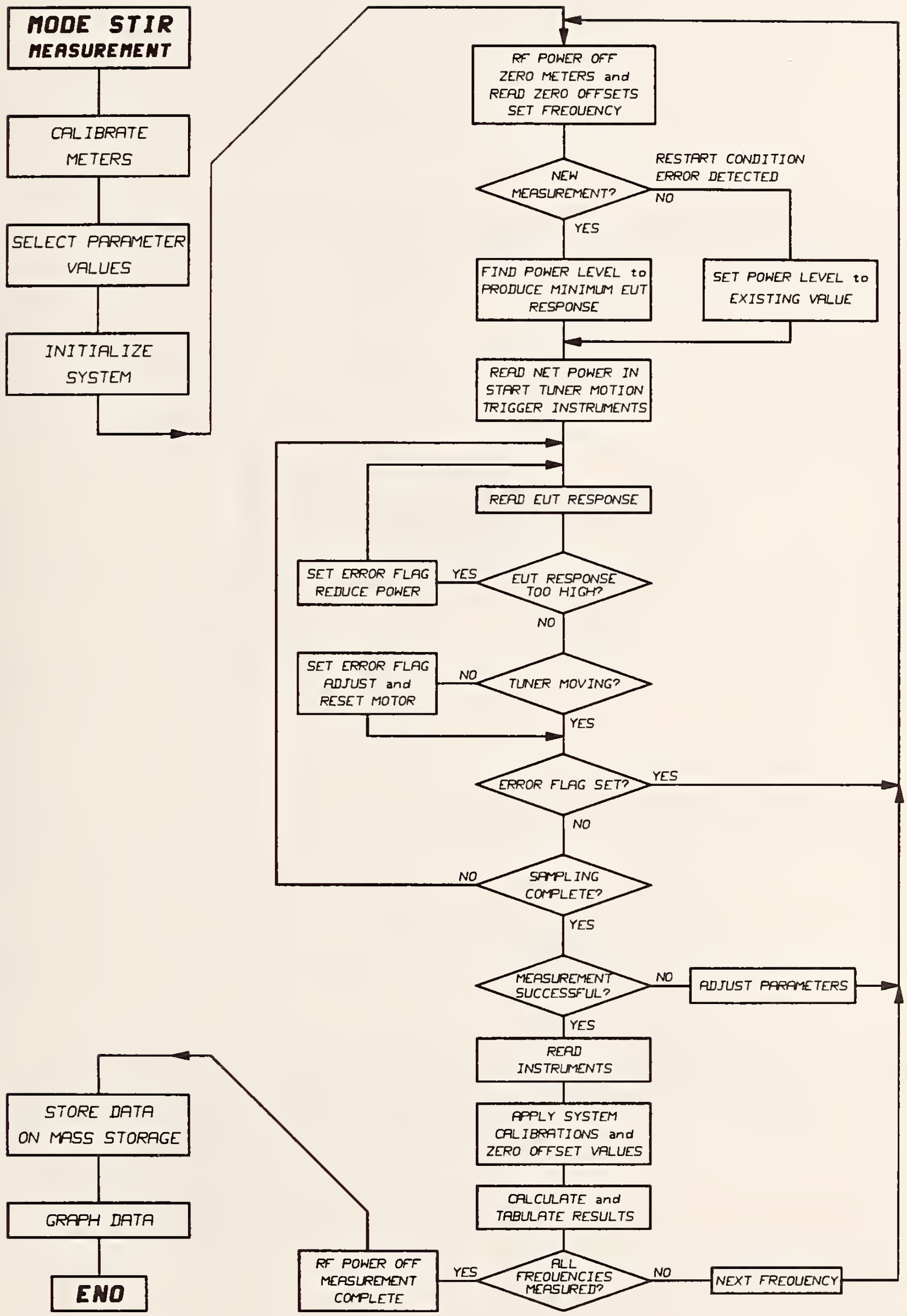


Figure 4.4 Flow diagram for mode-stirred measurements.

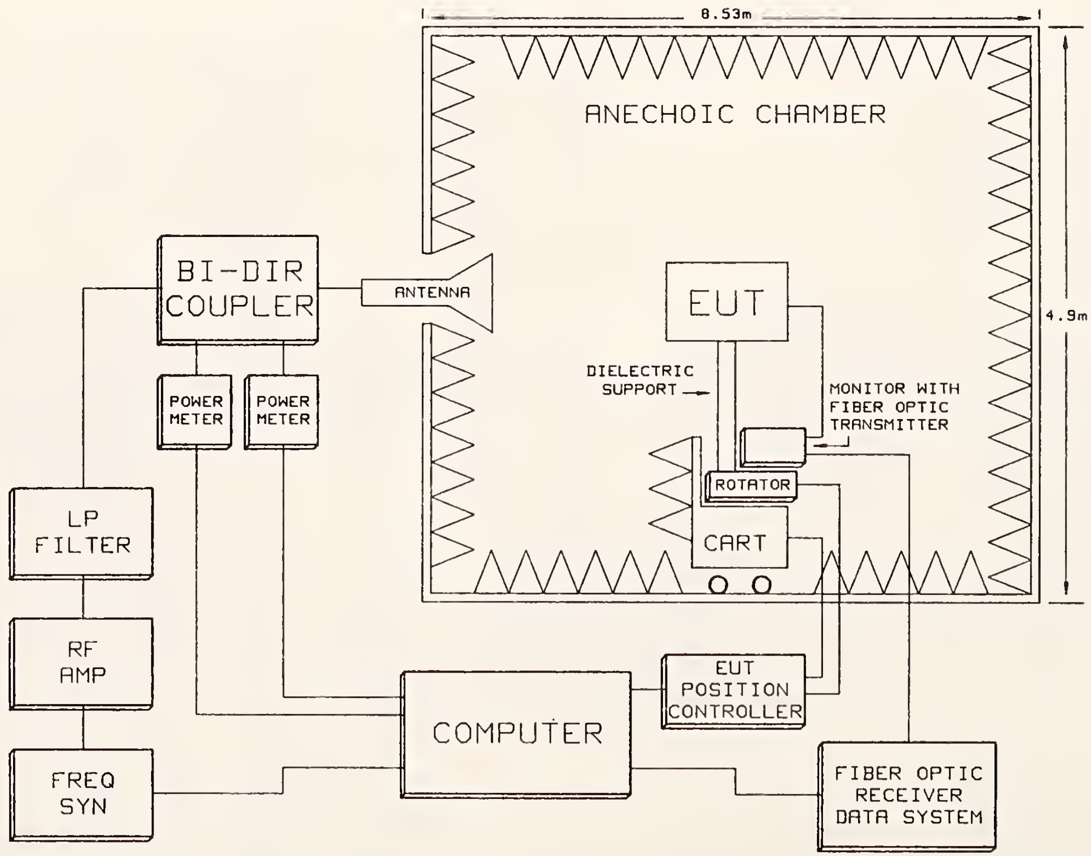


Figure 5.1 Block diagram of NBS anechoic chamber EMC/EMI measurement system. Side view of chamber. The outside width is 6.7 m.

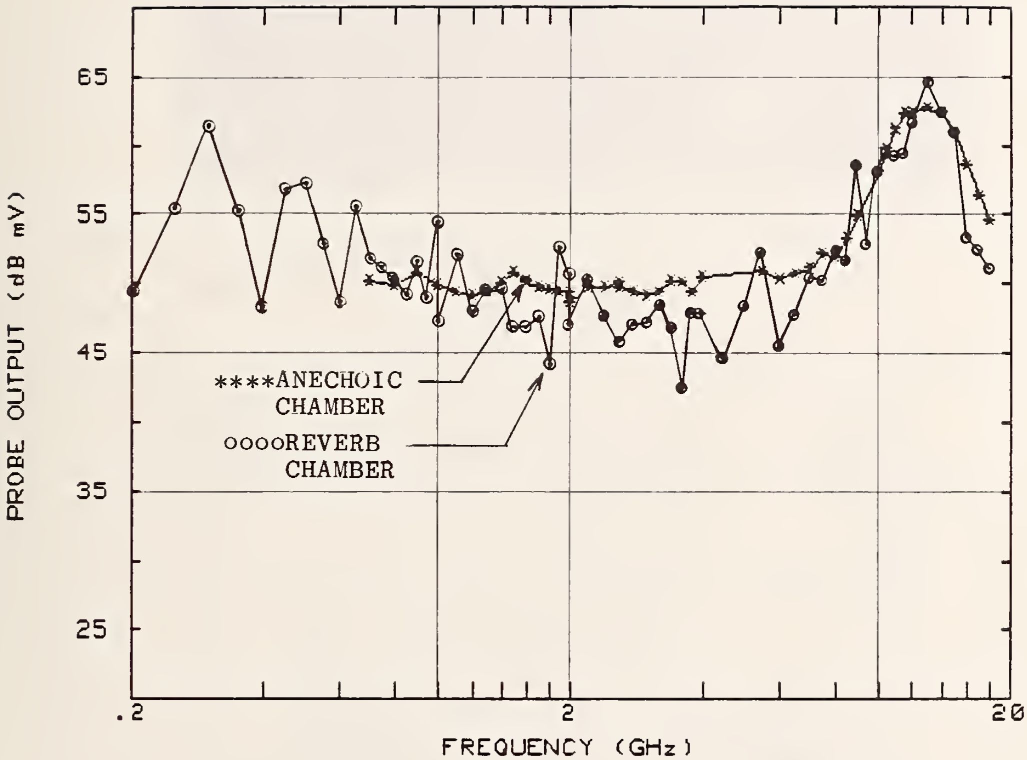


Figure 5.2 Comparison of 1 cm dipole probe's peak responses to EM field established inside NBS reverberation and anechoic chambers. Output normalized to E-field exposure of 37 dB V/m.

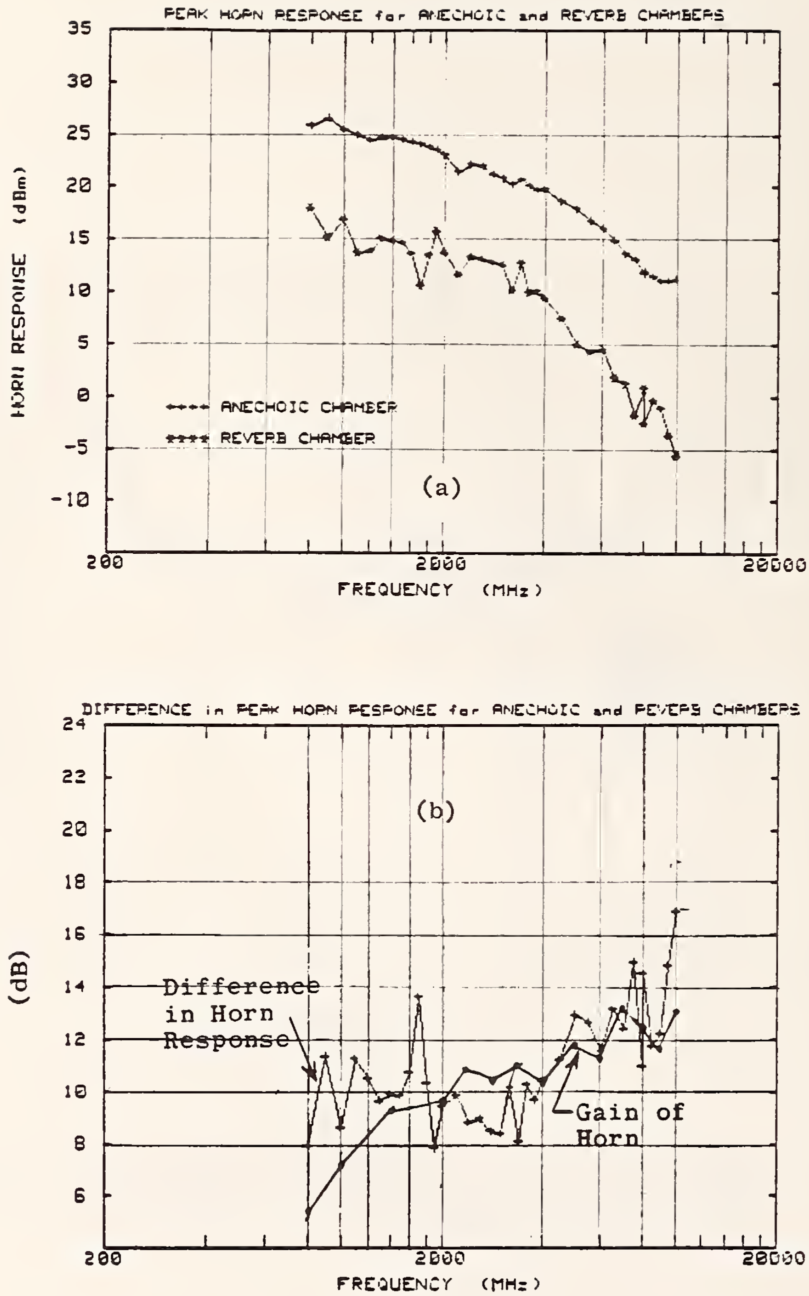


Figure 5.3 Comparison of ridged horn's peak responses to EM field established inside NBS reverberation and anechoic chambers. Output from horn normalized to exposure E-field of 37 dB V/m. a) Antenna output versus frequency, b) Difference in output responses of ridged horn measured in NBS reverberation and anechoic chambers compared to calibrated gain of horn.

Figure 5.4 Photograph of 12 cm x 18 cm x 36 cm rectangular TEM cell with 5.1 cm x 5.1 cm aperture.

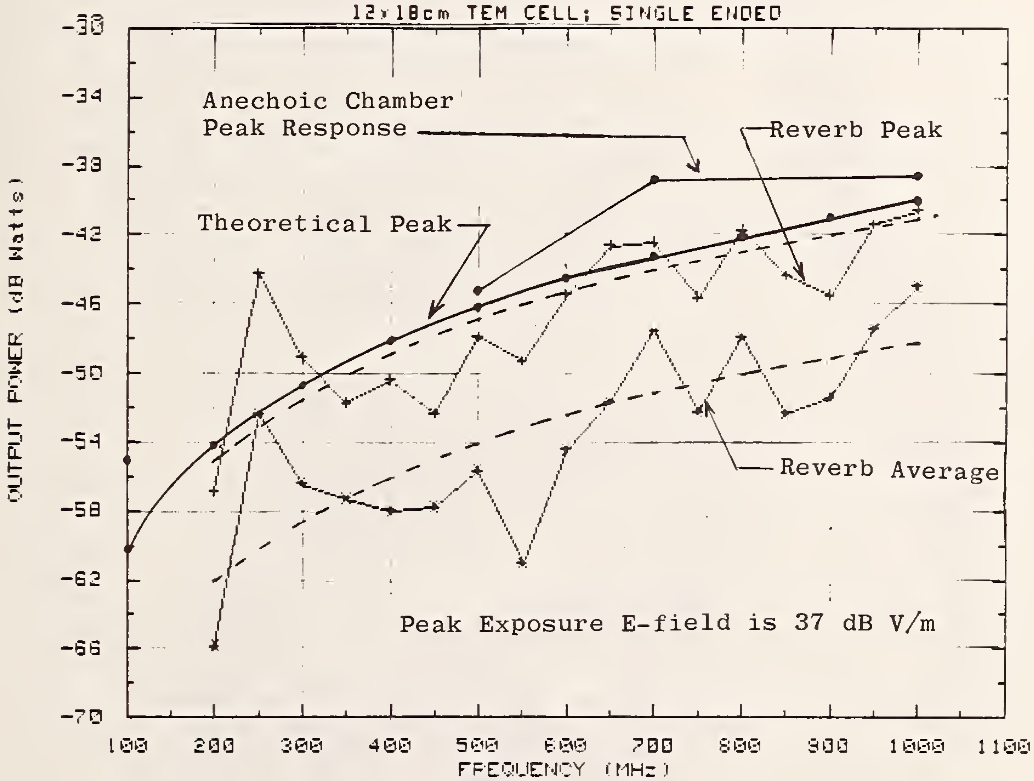


Figure 5.5 Comparison of power coupled to one port of 12 cm x 18 cm x 36 cm TEM cell with 5.1 cm x 5.1 cm aperture placed inside NBS reverberation and anechoic chambers.

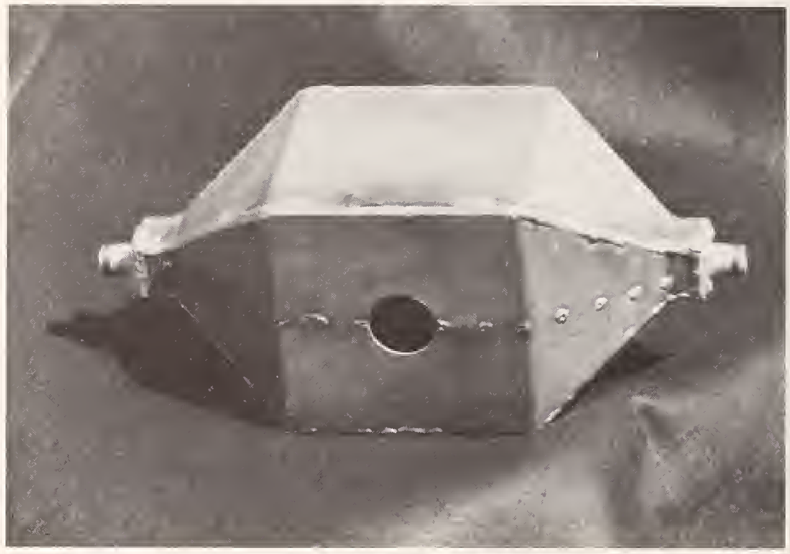


Figure 5.6 Photograph of 12 cm x 12 cm x 24 cm rectangular TEM cell with 3.1 cm diameter aperture.

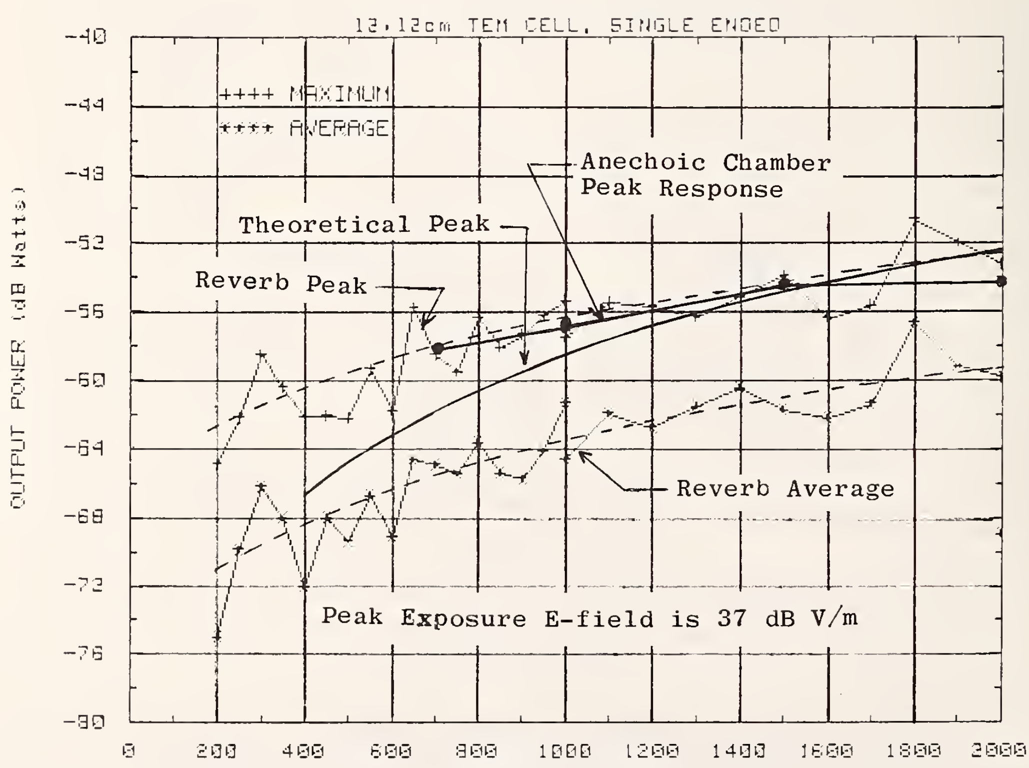


Figure 5.7 Comparison of power coupled to one port of 12 cm x 12 cm x 24 cm TEM cell with 3.1 cm diameter aperture placed inside NBS reverberation and anechoic chambers.

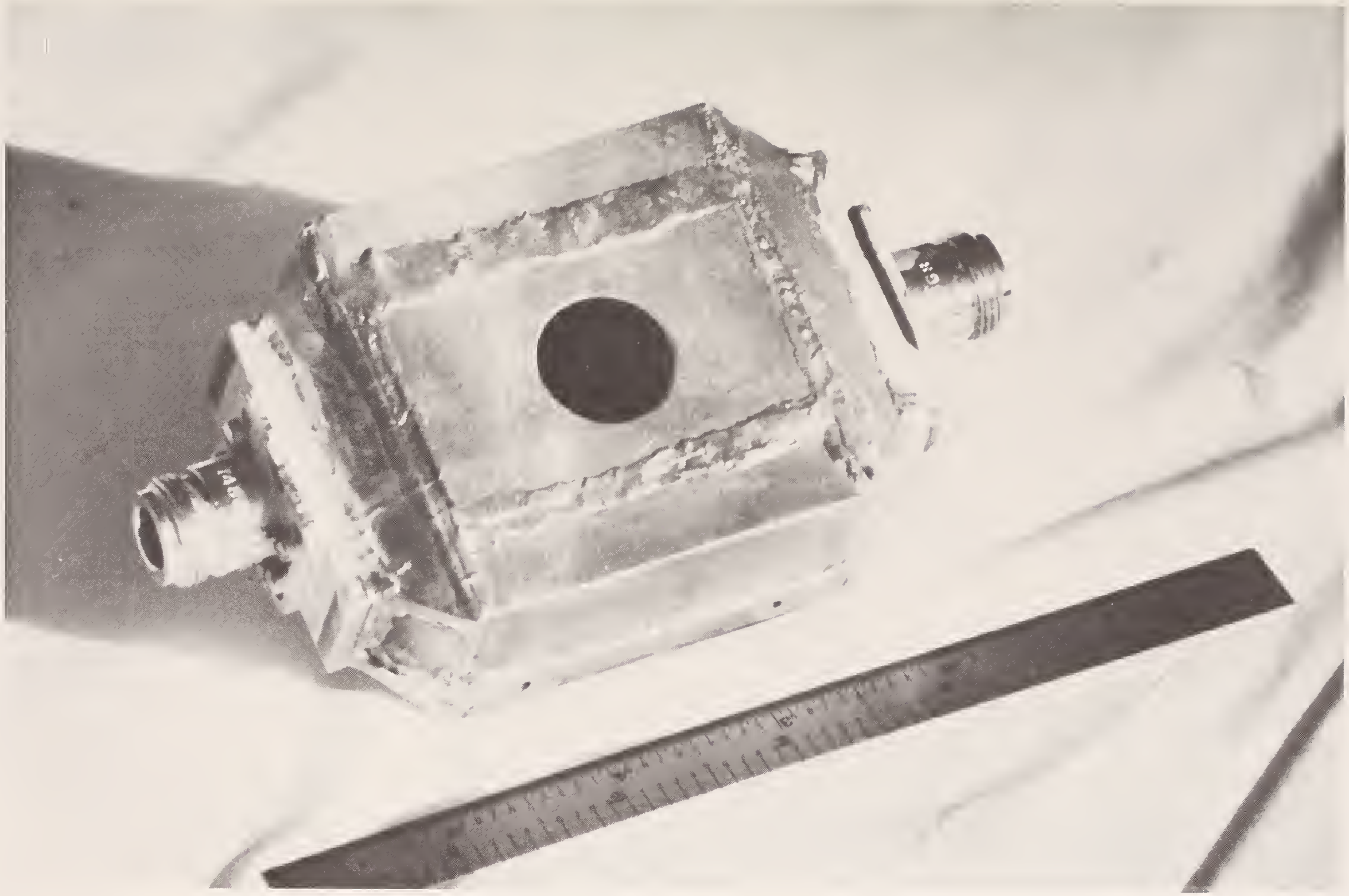


Figure 5.8 Photograph of 3.0 cm x 6.0 cm x 11.4 cm rectangular TEM cell with 1.4 cm diameter aperture.

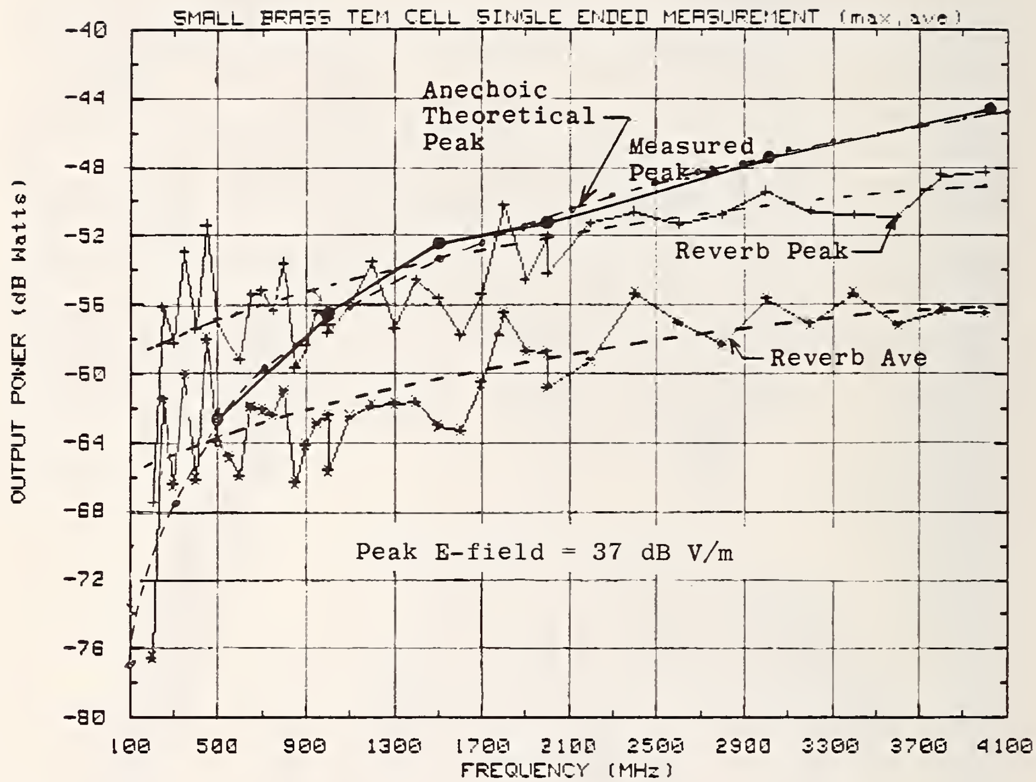
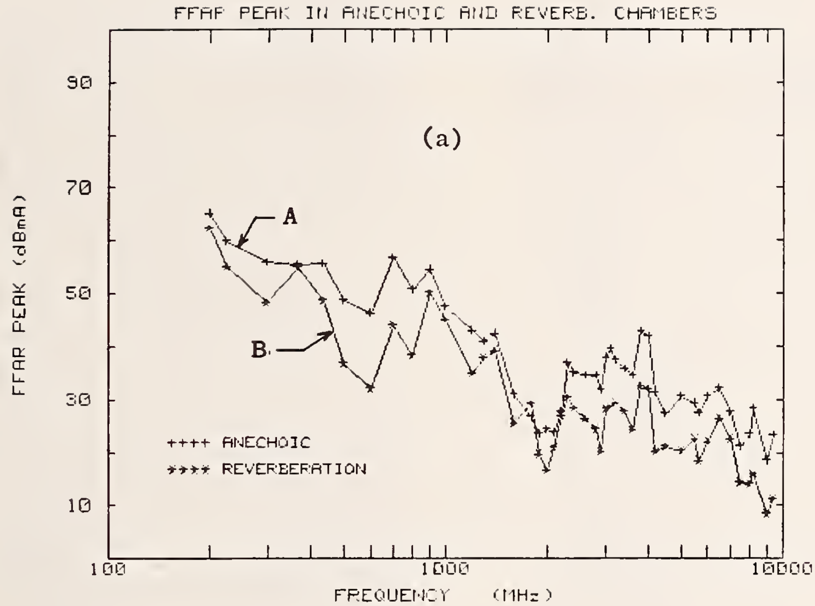


Figure 5.9 Comparison of power coupled to one port of 3.0 cm x 6.0 cm x 11.4 cm TEM cell with 1.4 cm diameter aperture placed inside NBS reverberation and anechoic chambers.

Figure 5.10 Photograph of modified 7.0 cm Folding Fin Aircraft Rocket inside NBS reverberation chamber.

Figure 5.11 Photograph of modified 7.0 cm Folding Fin Aircraft Rocket inside NBS anechoic chamber.



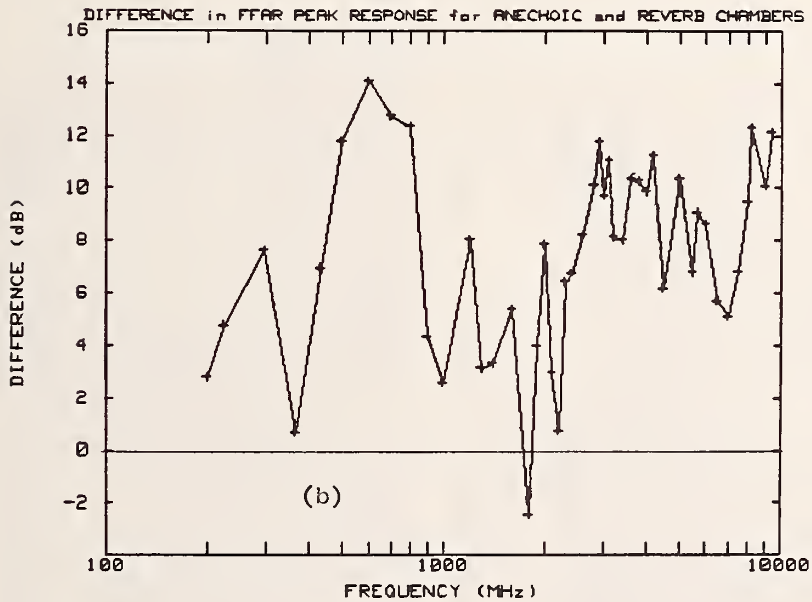


Figure 5.12 Comparison of 7.0 cm modified FFAR thermocouple responses to EM field established inside NBS reverberation and anechoic chambers. Data normalized to exposure power density of 10 mW/cm^2. a) Thermocouple output vs frequency. b) Difference in thermocouple output measured in NBS reverberation and anechoic chambers.

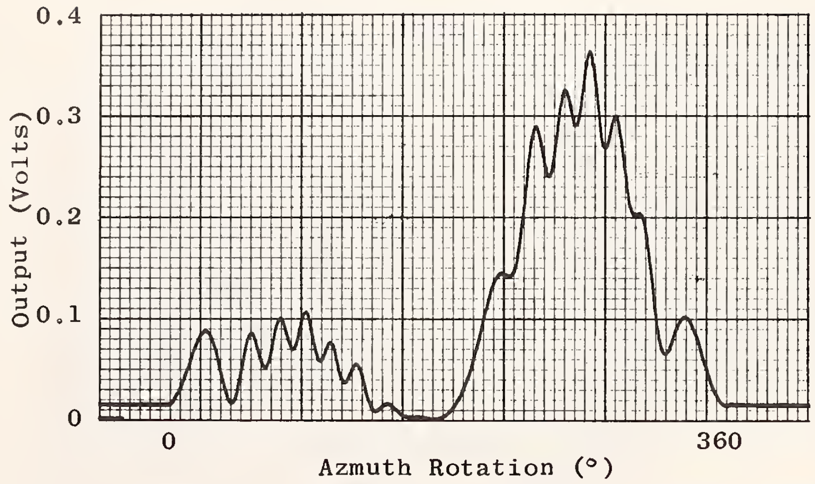


Figure 5.13a 700 MHz, Hor. Polar., Roll = 330°

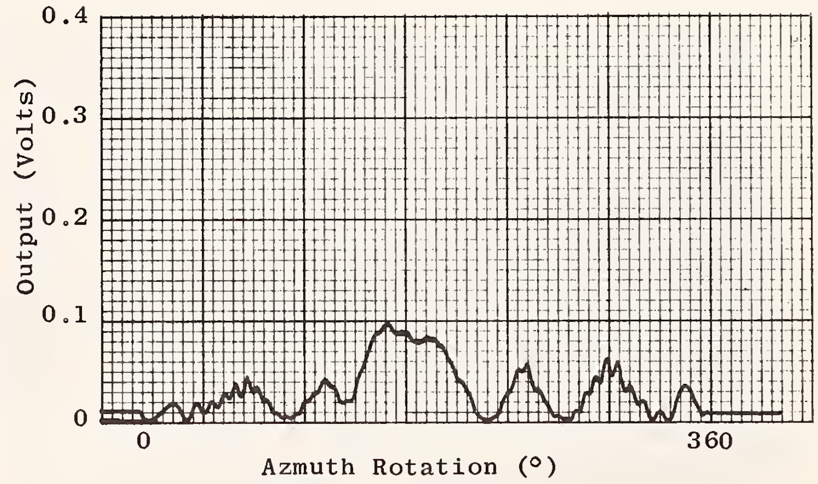


Figure 5.13b 1800 MHz, Hor. Polar., Roll = 0°

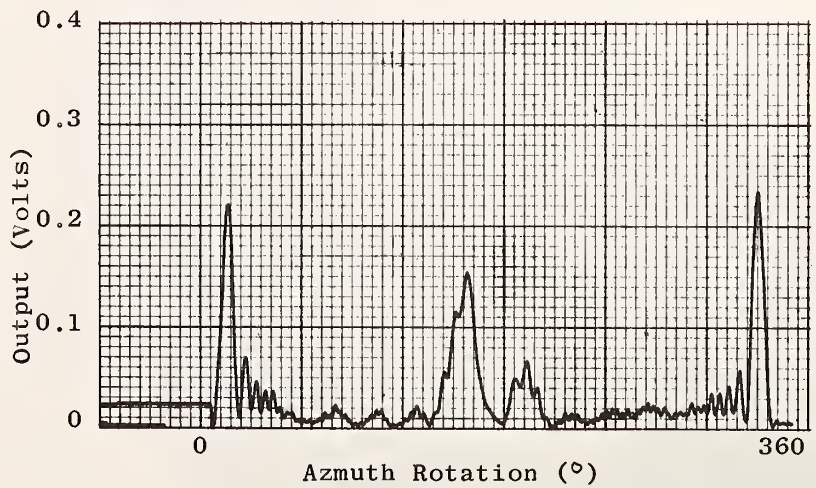


Figure 5.13c 3800 MHz, Hor. Polar., Roll = 0°

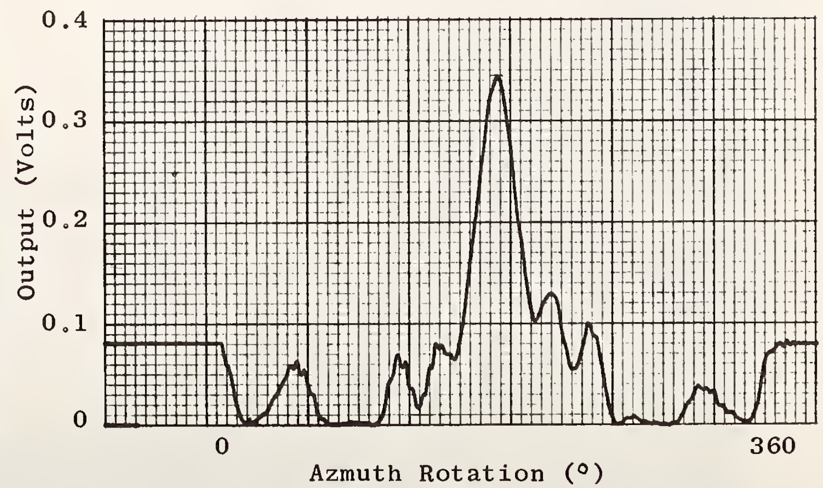


Figure 5.13d 3800 MHz, Vert. Polar., Roll = 0°

Figure 5.13 Examples of azimuth patterns of 7.0 cm modified FFAR thermocouple response taken in NBS anechoic chamber.

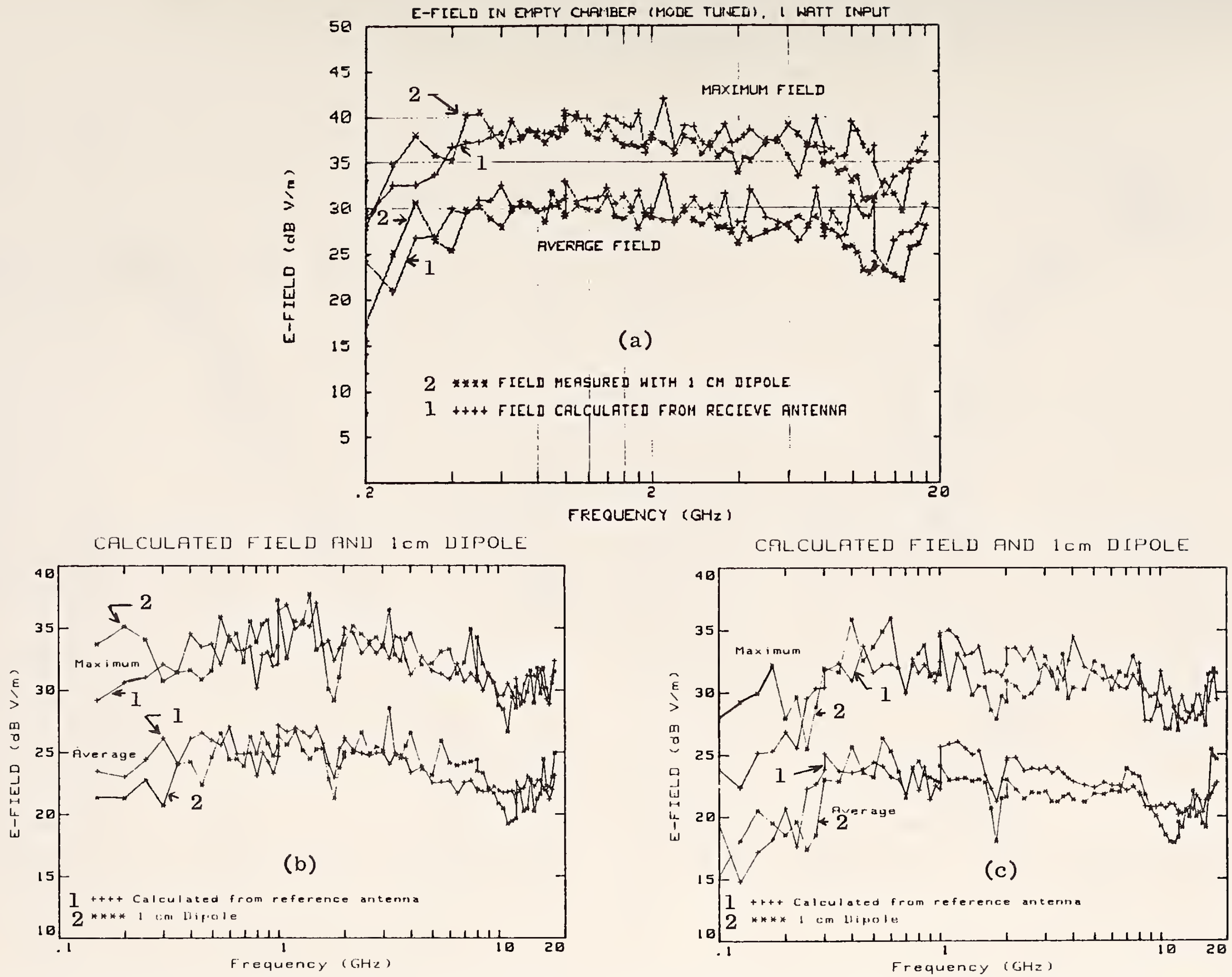


Figure 5.14 Comparison of the average and maximum E-field strengths inside the NBS and NSWC reverberation chambers determined for 1 W net input power using 1) reference antenna received power measurements, and 2) calibrated 1 cm dipole probe measurements. (a) NBS chamber, (b) NSWC half chamber, and (c) NSWC full chamber.

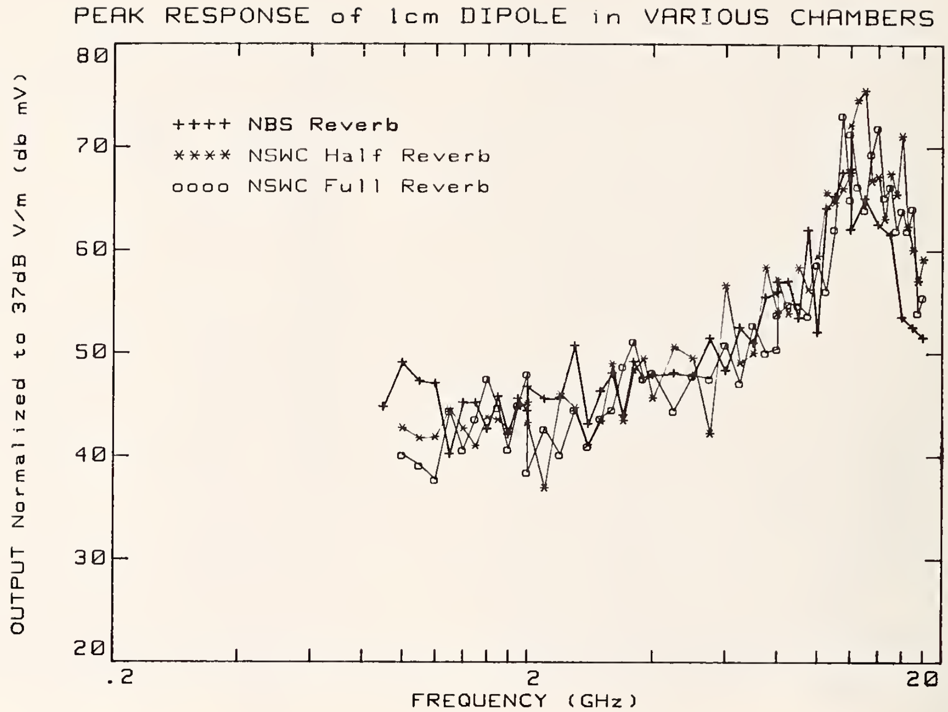


Figure 5.15 Comparison of 1 cm dipole probe's peak response to normalized E-field of 37 dB V/m using NBS and NSWC reverberation chambers.

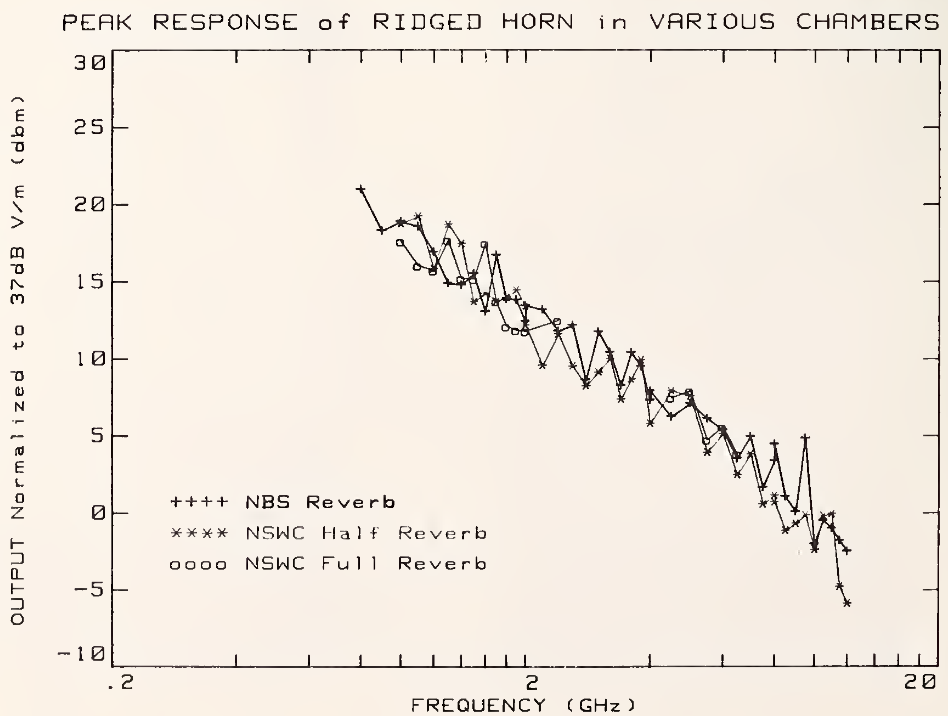


Figure 5.16 Comparison of ridged horn's peak responses to normalized exposure E-field of 37 dB V/m using NBS and NSWC reverberation chambers.

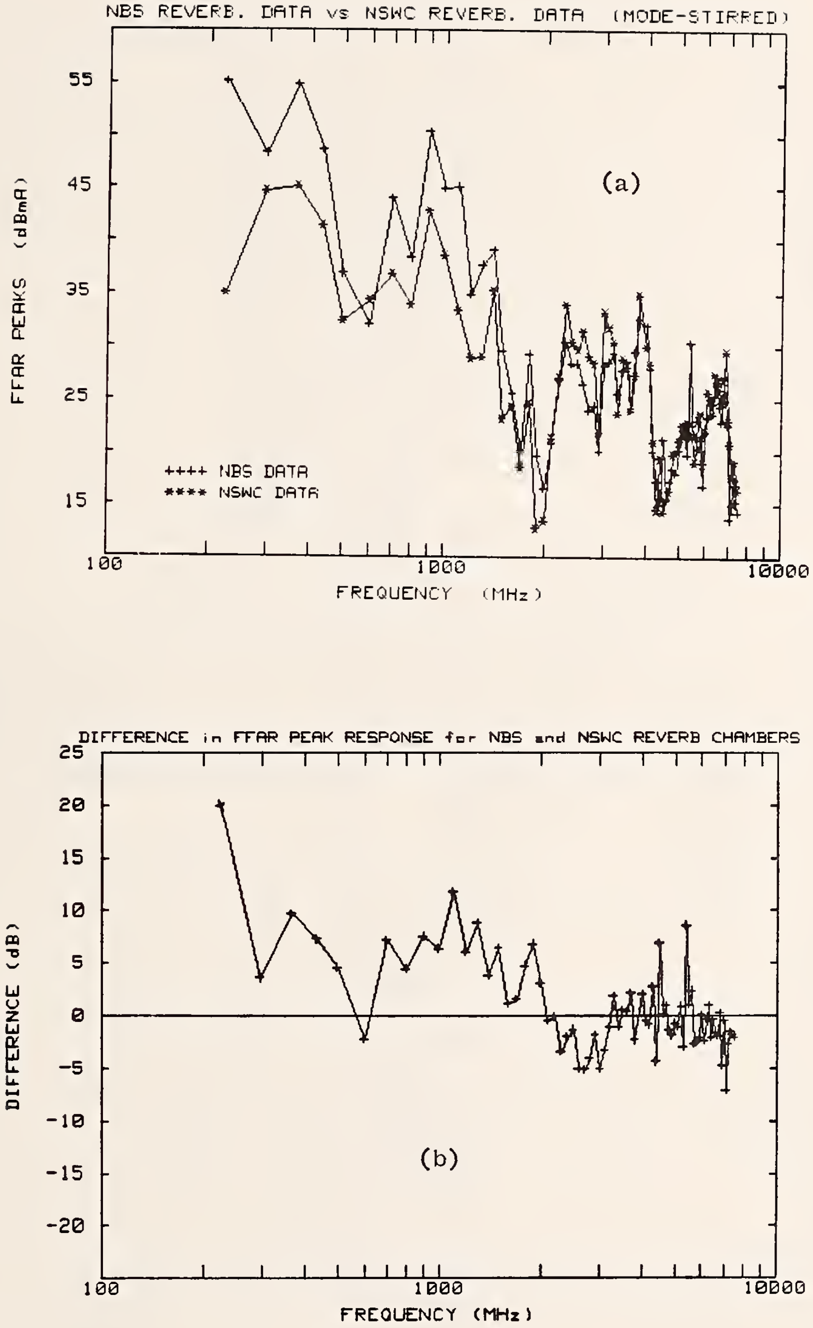
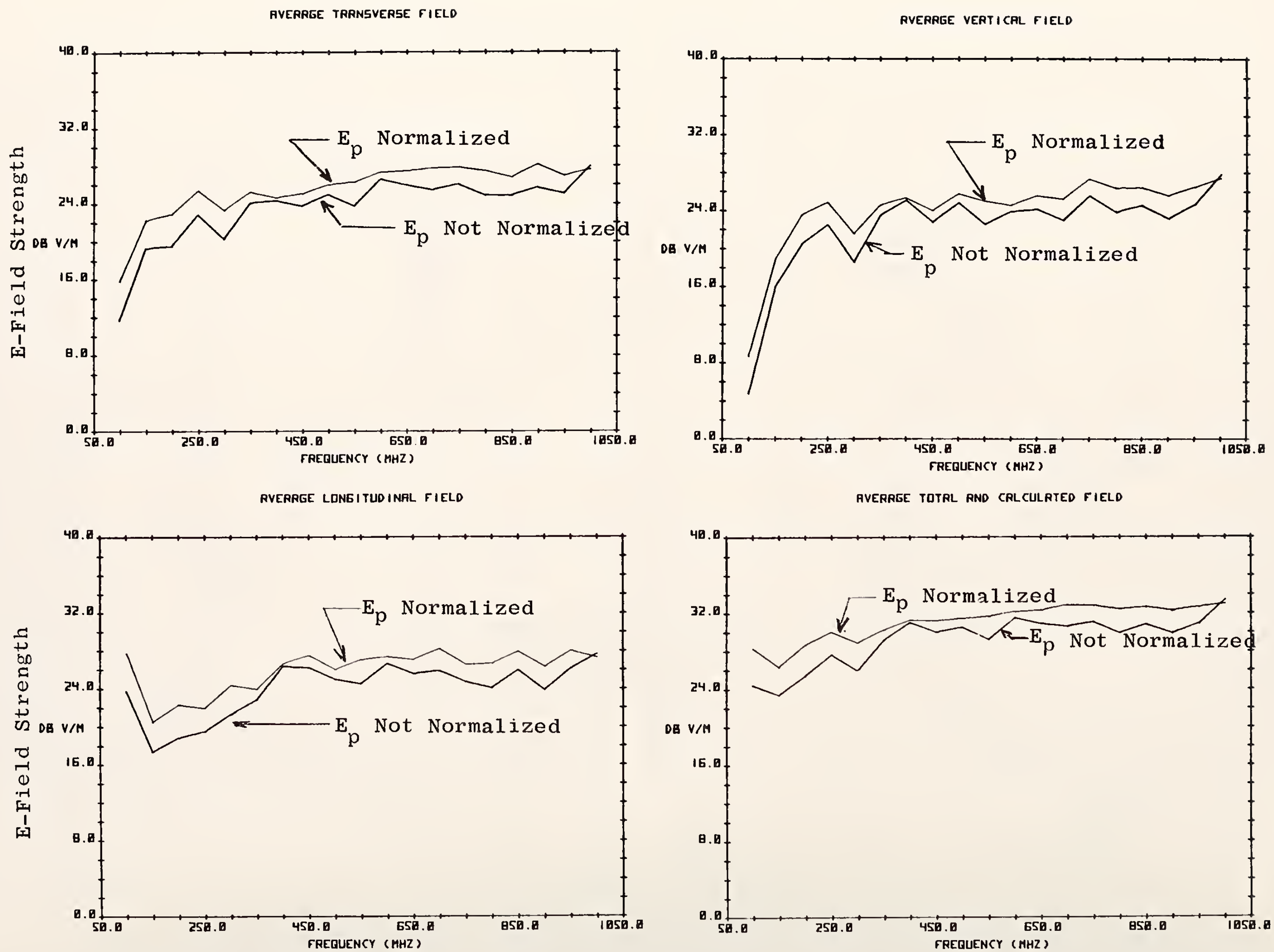


Figure 5.17 Comparison of 7.0 cm modified FFAR thermocouple responses to EM field established inside NBS and NSWC half reverberation chambers. Data normalized to exposure power density of 10 mW/cm^2. a) Thermocouple output vs frequency. b) Difference in thermocouple output measured in NBS and NSWC reverberation chambers.



(a)

Figure 6.1 Sheet 1 of 2

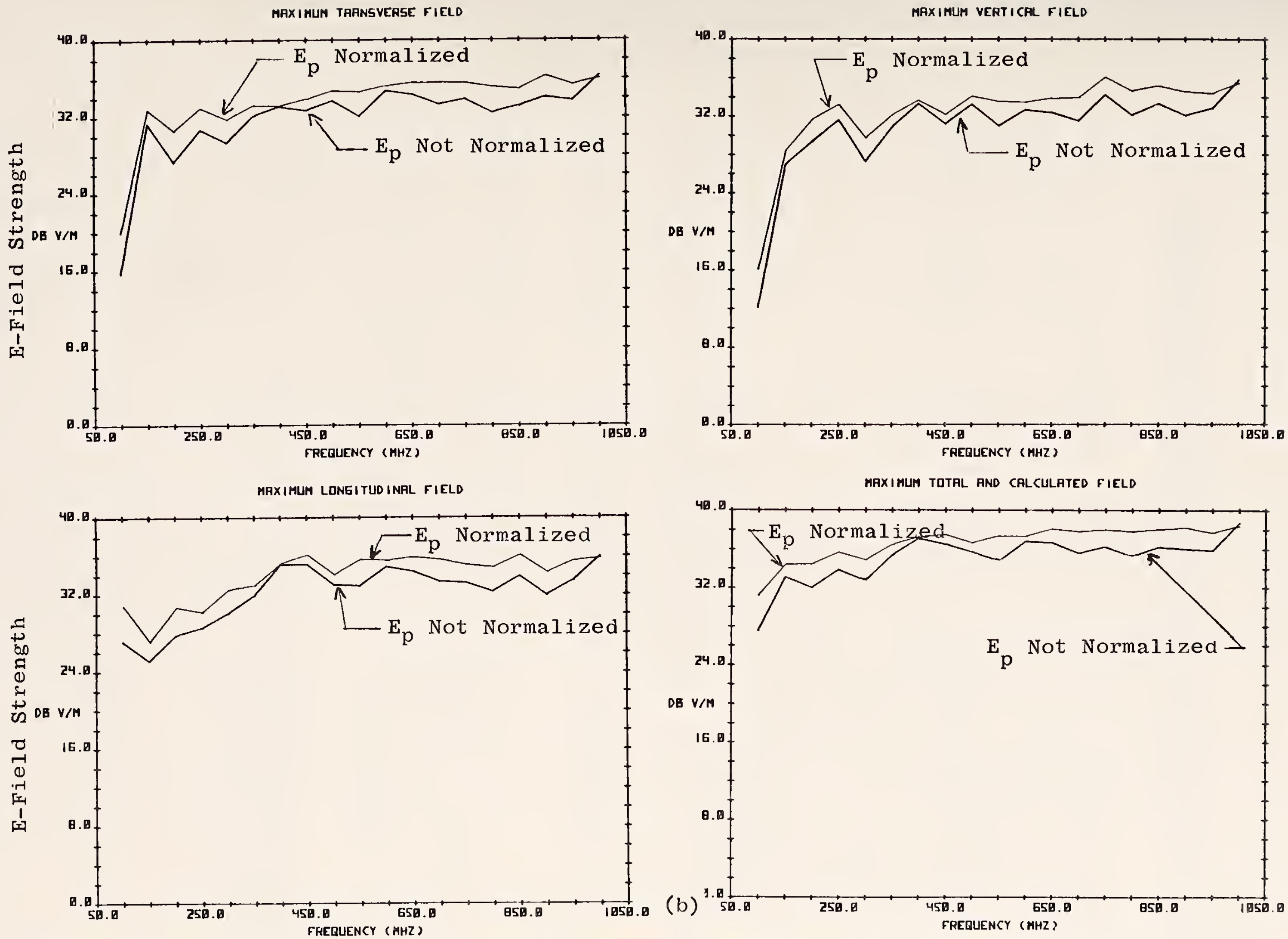


Figure 6.1 E-field strength measured inside NBS reverberation chamber using array of 7 NBS isotropic probes: (a) average, and (b) maximum. Comparison shown between results obtained before and after normalization of measurements to correct for changes in net input power. Normalized data corrected for net input power of 1.0 Watt. Chamber excitation antenna is log periodic. E_p is average field strength determined from 7 probes.

Table 6.1 Summary and estimates of measurement uncertainties for determining field strength inside NBS reverberation chamber - Mode Tuned (200 MHz - 2.0 GHz)

Source of Error	200 MHz Ave.	200 MHz Max.	500 MHz Ave.	500 MHz Max.	1.0 GHz Ave.	1.0 GHz Max.	2.0 GHz Ave.	2.0 GHz Max.
	Error (dB)							
1) Measuring Received Power								
Cable Loss	± 0.05		± 0.05		± 0.05		± 0.10	
Attenuator Calibration	± 0.10		± 0.10		± 0.10		± 0.10	
Antenna Efficiency	± 0.05		± 0.05		± 0.05		± 0.10	
Power Meter Calibration	± 0.20		± 0.20		± 0.20		± 0.20	
Total	± 0.40		± 0.40		± 0.40		± 0.50	
2) Receiving Power Mismatch (See Figure 6.1)	-2.8	-5.1	-1.5	-3.4	-0.7	-1.5	-0.3	-0.7
3) Mixing/Sampling Efficiency								
Spatial Field Uniformity (see figure 2.27)	± 8.0		± 5.0		± 3.0		± 2.0	
Limited Sample Size (see Table 6.4)	±0.2	±0.5	±0.2	±0.5	±0.2	±1.5	±0.3	±1.0
Total	±8.2	±8.5	±5.2	±5.5	±3.2	±4.5	±2.3	±3.0
4) Wave Impedance ≠ 120π (see Figure 2.25)	-2.8 +2.0	-2.8 +6.0	-2.0 +2.0	-2.0 +6.0	-2.0 +2.0	-2.0 +4.5	-2.0 +2.0	-2.0 +3.0
Total Worst Case Error	-14.2 +10.6	-16.8 +14.9	-9.1 +7.6	-11.3 +11.9	-6.3 +5.6	-8.4 +9.4	-5.1 +4.8	-6.2 +6.5
RSS Error	-9.1 +8.5	-10.3 +10.4	-5.8 +5.6	-6.8 +8.1	-3.9 +3.8	-5.2 +6.4	-3.1 +3.1	-3.7 +4.3
5) Failure to Correct for Input Power Variations (Transmit Mismatch Error)	-4.0		-3.0		-2.0		-1.0	

Table 6.2 Summary and estimates of measurement uncertainties for determining field strength inside NBS reverberation chamber - Mode Stirred (2.0 GHz - 18.0 GHz)

Source of Error	Error (dB) 2.0 GHz Ave. Max.	4.0 GHz Ave. Max.	8.0 GHz Ave. Max.	12.0 GHz Ave. Max.	18.0 GHz Ave. Max.
1) Measuring Received Power					
Cable Loss	± 0.10	± 0.10	± 0.15	± 0.15	± 0.20
Attenuator Calibration	± 0.10	± 0.15	± 0.15	± 0.20	± 0.20
Antenna Efficiency	± 0.10	± 0.15	± 0.15	± 0.20	± 0.20
Spectrum Analyzer Cal.	± 1.50	± 1.50	± 1.50	± 1.50	± 1.50
Sub Total	± 1.80	± 1.90	± 1.95	± 2.05	± 2.10
2)Receiving Power Mismatch (see Figure 6.1)	-0.8	-0.8	-0.8	-1.0	-1.8
3) Mixing/Sampling Efficiency					
Spatial Field Var.	± 2.0	± 1.0	± 0.5	± 0.2	± 0.2
Limited Sample Size (see Table 6.4)	±0.1 ±0.3	±0.2 ±0.5	±0.3 ±0.7	±0.3 ±1.0	±0.3 ±1.5
Sub Total	±2.1 ±2.3	±1.2 ±1.5	±0.8 ±1.5	±0.5 ±1.2	±0.5±1.7
4) Wave Imped ≠ 120π	Average ≦ ±2.0, -2.0 ≧ Maximum ≦ +3.0				
5) Failure to Correct for Input Power Var.	-0.8	-0.8	-0.8	-1.0	-1.8
Total(Worst Case)Error	-7.5 -7.7 +5.9 +7.1	-6.7 -7.0 +5.1 +6.4	-6.4 -6.8 +4.8 +6.2	-6.6 -7.3 +4.6 +6.3	-8.2 -9.4 +4.6 +6.8
RSS Error	-3.6 -3.7 +3.4 +4.2	-3.1 -3.3 +3.0 +3.9	-3.1 -3.2 +2.9 +3.8	-3.2 -3.4 +2.9 +3.8	-3.9 -4.2 +2.9 +4.0

Table 6.3 Estimates of impedance mismatch uncertainties for received power measurements

Frequency GHz	VSWR Source Ave	VSWR Source Max	VSWR Load Max	Mismatch Error (dB) Ave	Mismatch Error (dB) Max
0.2	5.0	10.0	1.10	-2.83	-5.15
0.5	3.0	6.0	1.10	-1.46	-3.40
1.0	2.0	3.0	1.10	-0.66	-1.46
2.0	1.5	2.0	1.10	-0.27	-0.66
2.0	2.0	2.0	1.20	-0.81	-0.81
4.0	2.0	2.0	1.20	-0.81	-0.81
8.0	2.0	2.0	1.20	-0.81	-0.81
12.0	2.0	2.0	1.30	-0.95	-0.95
18.0	2.5	2.5	1.50	-1.77	-1.77

Table 6.4 Estimates of uncertainties due to limiting number of tuner positions (sample size).

Frequency GHz	Error due to limiting Sample Size Ave/Max (dB) Number of Tuner Positions 50	100	200	400	800
0.2	0.2/0.8	0.2/0.5	--	--	--
0.5	0.6/3.6	0.5/2.0	0.2/0.5	--	--
1.0	--	1.0/4.0	0.2/1.5	0.2/0.5	0.1/0.2
2.0	--	--	0.5/3.0	0.3/1.0	0.1/0.5
4.0	--	--	--	0.5/3.0	0.2/1.0
8.0	--	--	--	--	0.5/3.0

APPENDIX

Computer Programs for
Reverberation Chamber Immunity Measurements

```
100!  RE-STORE "ModeTune01"
102   ! Original:  5 May 1984  G. Koepke  (303) 497-5766
104   ! Revision: 21 Feb 1986, 09:20
106   !
108   ! This measurement routine will operate the REVERBERATION CHAMBER
110   ! using MODE TUNED techniques.  The tuner is stepped in discrete steps
112   ! and measurements are performed at each step. In this version ALL
114   ! frequencies are measured at each tuner step before proceeding
116   ! to the next step.  Both the case of susceptability (power supplied
118   ! by a signal generator) and emissions (power supplied by EUT) can be
120   ! handled.  This program will handle EUT emissions by not measuring
122   ! the net input power and recording the received power as detected
124   ! by the reference antenna.  Duplicate measurements are required to
126   ! inject an 'equivalent' (will be normalized later) power to set
128   ! up the same response using the transmit antenna as was measured
130   ! with the EUT only.  This method will determine the total power
132   ! radiated by the EUT.
134   !
136   ! The program will also handle the case where the tuner is not stepped,
138   ! as in a TEM cell or ANECHOIC chamber where a single measurement
140   ! is needed.  The data is condensed for this case.
142   !
144   ! Coupler, cable loss, and Power meter head corrections are applied
146   ! immediately to the measured data.  These computations must be verified
148   ! by examining program lines that begin with the line label
150   ! Apply_cal_data, merely execute the EDIT command as shown.
152   !
154   ! EDIT Apply_cal_data
156   !
158   ! The measurement data are saved on disk for processing.  It may also
160   ! be tabulated as the measurement proceeds by toggling a print flag
162   ! that is shown at the start of each tuner step.
164   !
166   ! ............................................................
168   ! Features:    1) NBS multiprobe system
170   !              2) HP 436 and/or HP 438 power meters
172   !              3) HP 3456 or 3478 DVMs
174   !              4) HP 8566 Spectrum Analyzer (Power only)
176   !              5) HP relay actuator for RF switching
178   !              6) Superior Electric Stepping motor control
180   !              7) Either of HP8660A or HP8672A signal source.
182   !
184   ! ............... Current Configuration .....................
186   !
188   ! Perform preliminary emissions experiments in the chamber.
190   !
192   !    Standard items:    1) Incident Power to transmit antenna
194   !                       2) Reflected power from transmit antenna
196   !                       3) Received power from reference antenna
198   !
200   ! Measure output of:    4) Any number of NBS probes via system.
202   !                          [not used for emission tests]
204   !
206   ! ............... Special Notes .............................
208   !
210   !
212   !
214   !
216   !
```

```
218     !
220     !
222     ! ****************** MAIN PROGRAM ****************************
224     !
226     OPTION BASE 1
228     DEG
230     OUTPUT 2 USING "K,#";"SCRATCH KEYX"
232     CALL Wipe_clean
234     GOSUB Dim_variables       ! Dimension all variables, set selected values.
236     GOSUB Load_cal_data       ! Load all calibration data for pads & cables.
238  New_measurement:!
240     PRINTER IS CRT
242     DISP CHR$(129)
244     GOSUB Initial_values      ! Preset all parameters and access menu.
246     GOSUB Sig_gen_subs        ! Load selected Signal Generator subs
248                               ! and selected coupler calibraton data.
250     GOSUB Fillcalibration     ! Fill lookup table for calibration values.
252     GOSUB Do_measurements     ! <-- read it again
254     GOSUB Die_gracefully      ! Delete signal generator subs from memory
256     PRINTER IS CRT
258     DISP " ";TIME$(TIMEDATE);" ";DATE$(TIMEDATE);" ....PROGRAM FINISHED,";
260     DISP "  'CONTINUE' to repeat."
262     PAUSE
264     GOTO New_measurement
266     STOP
268     !
270     ! ******************** END of MAIN PROGRAM ******************
272     !
274     ! //////////////////*** DIMENSION VARIABLES ***////////////////
276     !
278  Dim_variables:!
280     !
282     COM /Parameters/ REAL Fstart,Fstop,Fstep
284     COM /Parameters/ REAL Min_eut,Max_eut,Min_pwr,Max_pwr,Time_eut
286     COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm
288     COM /Parameters/ INTEGER Search_eut,Search_pwr,Re_run
290     COM /Parameters/ INTEGER Begin_step,Total_steps,Total_meters
292     COM /Parameters/ Run_id$[10],Measmt_id$[160],Time_date$[30]
294     COM /Parameters/ Meter_defns$(40)[40],Operator_name$[28],Test_type$[20]
296     COM /Parameters/ Coupler_id$[10],Generator_id$[10]
298     !
300     COM /Probe_system/ INTEGER Sys_size,Total_chans,Probe_addr(30,3)
302     COM /Probe_system/ INTEGER Top_probe,Fcal_pts,Pr_avgs
304     COM /Probe_system/ INTEGER Probe_volts(30),Overrange(30)
306     COM /Probe_system/ INTEGER Probe_zero(30),REAL Probe_v_m(30)
308     COM /Probe_system/ REAL Amplitude_cal(11,3,5),Freq_cal(11,3,13,2)
310     COM /Probe_system/ REAL Readtime(30),Freq_crib(13,2)
312     !
314     COM /Interrupts/ INTEGER Intr_prty
316     COM /Motor_menu/ Motion_type$[10],Rev_rate,INTEGER Tuner_steps
318     COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
320     COM /Files/ Sourcedisk$[20],Outdisk$[20],Filename$[80]
322     !
324     !...........Cable and etc. calibration files..........
326     !
328     DIM Baddata_id$(15)[40]
330     INTEGER Calib_items
332     !
334     DIM Coup_inc(205,2),Coup_refl(205,2)
336     INTEGER Inc_pts,Refl_pts
```

```
338     REAL Coupinc,Couprefl
340     !
342     DIM Cable6_1(180,2),Cable6_6(180,2),Cable4_2(180,2),Cable4_4(180,2)
344     INTEGER C6_1pts,C6_6pts,C4_2pts,C4_4pts
346     REAL C6_1loss,C6_6loss,C4_2loss,C4_4loss
348     !
350     DIM Cable10_3(180,2),Cable10_5(180,2),Cable5_7(180,2)
352     INTEGER C10_3pts,C10_5pts,C5_7pts
354     REAL C10_3loss,C10_5loss,C5_7loss
356     !
358     DIM Cable_r4(80,2),Cable_r12(80,2)
360     INTEGER Cr4pts,Cr12pts
362     REAL Cr4loss,Cr12loss
364     !
366     DIM Pad_as6a(180,2),Pad_s6770(180,2),Pad_f5530(180,2)
368     INTEGER Pada_pts,Pads_pts,Padf_pts
370     REAL Pada_loss,Pads_loss,Padf_loss
372     !
374     DIM H_jct(77,2)    !Anzac Hybrid Junction
376     INTEGER Jct_pts
378     REAL Jct_loss
380     !
382     !............Other useful variables....................
384     !
386     DIM Cal_id$[40],Pwr_id$[2],Test$[160]
388     INTEGER Baddata,Dbm,Rf_on_off,Filesize,I,J,K,P
390     INTEGER Valid,Ftotal,File20steps,Beginstep,Endstep
392     INTEGER Printflag,Fcount,Too_hot,Printflag2,Steps
394     INTEGER Local_prty,Probe
396     !
398     INTEGER Fp436a1,Fp436a2,Fp438a1,Fp438a2,Fsa8566b
400     INTEGER Fv3456a1,Fv3456a2,Fv3478a1,Fr59306a
402     REAL Z3456a1,Z3456a2,Z3478a1
404     REAL V3456a1,V3456a2,V3478a1
406     !
408     ! ...... we need these initial values .................
410     !
412     Printer=701
414     Sourcedisk$=":INTERNAL,4,0"
416     Outdisk$=":INTERNAL,4,1"     ! or ":HP9133,700,0"
418     Intr_prty=6
420     Local_prty=Intr_prty
422 Bugs:!
424     Printflag=1         ! Print all setup parameters and calibration values.
426     Printflag2=1        ! Print raw data if both Printflag and Printflag2
428     Bug1=0
430     Bug2=0
432     Bug3=0
434     !
436     RETURN
438     !
440     ! ////////////////****INITIALIZE VARIABLES & I/O****/////////////
442     !
444 Initial_values:!
446     !
448     ASSIGN @Motor TO 706          !  Stepping motor
450     ASSIGN @Pwr1 TO 709           !  Power meters HP436a
452     ASSIGN @Pwr2 TO 710
454     ASSIGN @Dual_pwr1 TO 711      !  Power meters HP438a
456     ASSIGN @Dual_pwr2 TO 712
```

```
458    ASSIGN @Sig_gen TO 719          !  Signal generator  HP8660a or HP8672a
460    ASSIGN @Dvm1 TO 722             !  HP3456A Dvm.
462    ASSIGN @Dvm2 TO 723             !  HP3456A Dvm.
464    ASSIGN @Dvm3 TO 724             !  HP3478A Dvm.
466    ASSIGN @Gpio TO 12              !  NBS Multiprobe system
468    ASSIGN @Rly1 TO 717             !  HP relay actuator
470    ASSIGN @Spec_alzr TO 718        !  HP 8566 Spectrum Analyzer
472    !
474    !
476    Calib_items=15             ! 15 files for cables, coupler, and pad cals.
478    Pr_avgs=3                  ! Read Multiprobe 3 times and average.
480    Motion_type$="STEP"        ! or "CONTINUOUS" for MODE STIRRING.
482    Rev_rate=1.0               ! used only if MODE STIRRING operation.
484    Rf_on_off=1
486    !
488    CALL Measure_menu               ! Go and set up measurement parameters.
490    GOSUB Configure_instr           ! Turn on/off instruments as per menu
492    CALL Multiprobe_menu            ! Set up the 30 probe system.
494    DISP CHR$(129)
496    GOSUB Data_definition           ! Use above info to define data.
498    GOSUB Die_gracefully            ! To assure clean start.
500    Dbm=Low_dbm                     ! Initialize the Generator Level
502    Tuner_steps=Total_steps         ! Initialize the motor control
504    !
506    !----------------ALLOCATE THE RAW DATA MATRIX-----------------
508    Ftotal=INT((Fstop-Fstart)/Fstep)+1
510    IF Test_type$="OTHER (NO STEPS)" THEN
512        File20steps=Ftotal
514    ELSE
516        File20steps=20*Ftotal
518    END IF
520    ALLOCATE Rawdata(Total_meters+Total_chans+1,File20steps)
522    !------------------------------------------------------------
524    !
526    DISP "INSERT OUTPUT DATA DISK IN ";
528    SELECT Outdisk$
530    CASE ":INTERNAL,4,0"
532        DISP "RIGHT DRIVE, ";
534    CASE ":INTERNAL,4,1"
536        DISP "LEFT DRIVE, ";
538    END SELECT
540    DISP "and hit 'Continue-k5'."
542    BEEP
544    ON KEY 5 LABEL "Continue",Local_prty GOTO Datasaver
546 Zippity:GOTO Zippity
548 Datasaver:OFF KEY
550    GOSUB Save_configure
552    IF Printer<>CRT THEN
554        PRINTER IS Printer
556        PRINT RPT$("_",80)
558        PRINT
560        PRINTER IS CRT
562    END IF
564    GOSUB Print_vitals
566    DISP CHR$(12)
568    RETURN
570    !
572    ! ////////////////////////////////////////////////////////////////
574    !
576 Configure_instr:!
```

```
578    ! ... Instrument read flags, if set the meter will be read ...
580    !  Stepping motor controlled by Test_type$
582    !  Signal generator  HP8660a or HP8672a controlled by Test_type$
584    !  NBS Multiprobe system controlled by Total_chans
586    SELECT Test_type$
588    CASE "MODE TUNE REGULAR"
590        Fp436a1=0                    !  Power meter HP436a at addr 09
592        Fp436a2=0                    !  Power meter HP436a at addr 10
594        Fp438a1=1                    !  Power meter HP438a at addr 11
596        Fp438a2=0                    !  Power meter HP438a at addr 12
598        Fv3456a1=0                   !  HP3456A Dvm at addr 22
600        Fv3456a2=0                   !  HP3456A Dvm at addr 23
602        Fv3478a1=0                   !  HP3478A Dvm at addr 24
604        Fr59306a=0                   !  HP relay actuator at addr 17
606        Fsa8566b=1                   !  HP 8566 Spectrum Analyzer at addr 18
608    CASE "MODE TUNE EMISSIONS"
610        Fp436a1=0                    !  Power meter HP436a at addr 09
612        Fp436a2=0                    !  Power meter HP436a at addr 10
614        Fp438a1=0                    !  Power meter HP438a at addr 11
616        Fp438a2=0                    !  Power meter HP438a at addr 12
618        Fv3456a1=0                   !  HP3456A Dvm at addr 22
620        Fv3456a2=0                   !  HP3456A Dvm at addr 23
622        Fv3478a1=0                   !  HP3478A Dvm at addr 24
624        Fr59306a=0                   !  HP relay actuator at addr 17
626        Fsa8566b=1                   !  HP 8566 Spectrum Analyzer at addr 18
628    CASE "OTHER (NO STEPS)"
630        Fp436a1=0                    !  Power meter HP436a at addr 09
632        Fp436a2=0                    !  Power meter HP436a at addr 10
634        Fp438a1=1                    !  Power meter HP438a at addr 11
636        Fp438a2=0                    !  Power meter HP438a at addr 12
638        Fv3456a1=1                   !  HP3456A Dvm at addr 22
640        Fv3456a2=0                   !  HP3456A Dvm at addr 23
642        Fv3478a1=0                   !  HP3478A Dvm at addr 24
644        Fr59306a=0                   !  HP relay actuator at addr 17
646        Fsa8566b=0                   !  HP 8566 Spectrum Analyzer at addr 18
648    END SELECT
650    !
652    RETURN
654    !
656    ! ////////////////////****DATA DEFINITION****////////////////
658    !
660 Data_definition:      ! Set up the definitions of each meter reading,
662                       ! these are used later when processing
664                       ! SO be sure these are correct.
666                       ! The index corresponds to the Rawdata matrix row+1
668                       ! Frequency is always in row 1
670                       ! Meter 1 is in row 2, etc.
672                       !
674    SELECT Test_type$
676    CASE "MODE TUNE REGULAR"
678        Total_meters=3
680        Meter_defns$(1)="Incident Power (Watts)"
682        Meter_defns$(2)="Reflected Power(Watts)"
684        Meter_defns$(3)="Recieved Power (Watts)"
686    CASE "MODE TUNE EMISSIONS"
688        Total_meters=1
690        Meter_defns$(1)="Recieved Power (Watts)"
692    CASE "OTHER (NO STEPS)"
694        Total_meters=3
696        Meter_defns$(1)="Incident Power (Watts)"
```

```
698          Meter_defns$(2)="Reflected Power(Watts)"
700          Meter_defns$(3)="Probe Output (Volts)"
702      END SELECT
704      !
706      FOR P=1 TO Total_chans
708          Test$="Amp # "&VAL$(Probe_addr(P,1))&", 5cm Probe # "
710          Test$=Test$&VAL$(Probe_addr(P,2))&"-"
712          SELECT Probe_addr(P,3)
714          CASE 1
716              Test$=Test$&"X"
718          CASE 2
720              Test$=Test$&"Y"
722          CASE 3
724              Test$=Test$&"Z"
726          CASE 4
728              Test$=Test$&"Single"
730          CASE ELSE
732              Test$=Test$&"Error!"
734          END SELECT
736          IF LEN(Test$)>40 THEN
738              BEEP
740              DISP "ERROR in probe definitions"
742              PAUSE
744              Test$=Test$[1,40]
746          ELSE
748              Meter_defns$(P+Total_meters)=Test$
750          END IF
752      NEXT P
754      RETURN
756      !
758      !///////////////////////////////****DIE GRACEFULLY****////////////////
760      !
762 Die_gracefully: !
764      IF Bug1 THEN
766          PRINT TIME$(TIMEDATE);
768          PRINT RPT$("<",15);" DIE GRACEFULLY ";RPT$(">",15)
770      END IF
772      ON ERROR GOTO Delet_done1
774      SELECT Generator_id$
776      CASE "HP_8660A"
778          DELSUB Set_freq,Set_dbm,FNDigit10$,FNDigit3$,FNRev$
780      CASE "HP_8672A"
782          DELSUB Set_freq,Set_dbm
784      END SELECT
786 Delet_done1: !
788      OFF ERROR
790      ON ERROR GOTO Delet_done2
792      DEALLOCATE Rawdata(*),Adjust(*)
794 Delet_done2: !
796      OFF ERROR
798      RETURN
800      !
802      ! ////////////////////////////////////////////////////////////////////
804      !
806 Sig_gen_subs:!
808      PRINTER IS CRT
810      PRINT TABXY(1,18);RPT$("*",15);
812      PRINT " LOAD SUB PROGRAMS & Coupler Calibrations ";RPT$("*",15)
814      Filename$=Generator_id$&Sourcedisk$
816      DISP " Put 'CALIBRATION DATA & SUB Program' disk in ";
```

```
818    SELECT Sourcedisk$
820    CASE ":INTERNAL,4,0"
822        DISP "RIGHT DRIVE, ";
824    CASE ":INTERNAL,4,1"
826        DISP "LEFT DRIVE, ";
828    END SELECT
830    DISP "hit 'Continue-k5'."
832    BEEP
834    ON KEY 5 LABEL "Continue",Local_prty GOTO Subloads
836    LOOP
838    END LOOP
840 Subloads:OFF KEY
842    DISP CHR$(12)
844    DISP " Signal Generator SUB PROGRAMS NOW LOADING "
846    ON ERROR CALL Errortrap
848    LOADSUB ALL FROM Filename$
850    OFF ERROR
852    DISP " Signal Generator SUB PROGRAMS LOADED "
854    WAIT 1
856    !
858    !-------------------------------------------------------------
860    !
862    IF Printflag THEN PRINTER IS Printer
864    IF Printflag THEN PRINT "CALIBRATION DATA FOR THE FOLLOWING IS LOADED:"
866    SELECT Coupler_id$
868    CASE "HP_778D"   ! 30 to 2000 MHz.
870        Filename$="HP_778D_f"&Sourcedisk$
872        CALL Enter_caldata(Filename$,Coup_inc(*),Cal_id$,Inc_pts)
874        Baddata_id$(1)=Cal_id$
876        IF Printflag THEN PRINT Cal_id$
878        Filename$="HP_778D_r"&Sourcedisk$
880        CALL Enter_caldata(Filename$,Coup_refl(*),Cal_id$,Refl_pts)
882        Baddata_id$(2)=Cal_id$
884        IF Printflag THEN PRINT Cal_id$
886    CASE "HP_11692D"   !  2 to 18 GHz
888        Filename$="HP11692D_f"&Sourcedisk$
890        CALL Enter_caldata(Filename$,Coup_inc(*),Cal_id$,Inc_pts)
892        Baddata_id$(1)=Cal_id$
894        IF Printflag THEN PRINT Cal_id$
896        Filename$="HP11692D_r"&Sourcedisk$
898        CALL Enter_caldata(Filename$,Coup_refl(*),Cal_id$,Refl_pts)
900        Baddata_id$(2)=Cal_id$
902        IF Printflag THEN PRINT Cal_id$
904    CASE "CH_130_4"    ! 1 to 30 MHz Anzac bi-directional
906        Filename$="CH130_4_f1"&Sourcedisk$
908        CALL Enter_caldata(Filename$,Coup_inc(*),Cal_id$,Inc_pts)
910        Baddata_id$(1)=Cal_id$
912        IF Printflag THEN PRINT Cal_id$
914        Filename$="CH130_4_r1"&Sourcedisk$
916        CALL Enter_caldata(Filename$,Coup_refl(*),Cal_id$,Refl_pts)
918        Baddata_id$(2)=Cal_id$
920        IF Printflag THEN PRINT Cal_id$
922    CASE ELSE
924        PRINT "COUPLER CALIBRATION DATA ERROR.....NOT DEFINED."
926        BEEP
928        PAUSE
930    END SELECT
932    !
934    !-------------------------------------------------------------
936    !
```

```
938     PRINT TABXY(1,18);RPT$(" ",80);
940     RETURN
942     !
944     ! ////////////////////////////////////////////////////////////////////
946     !
948 Load_cal_data:!
950     PRINT TABXY(1,18);RPT$("*",20);" LOAD CALIBRATION DATA ";RPT$("*",20)
952     DISP " Put 'CALIBRATION DATA & SUB Program' disk in ";
954     SELECT Sourcedisk$
956     CASE ":INTERNAL,4,0"
958         DISP "RIGHT DRIVE, ";
960     CASE ":INTERNAL,4,1"
962         DISP "LEFT DRIVE, ";
964     END SELECT
966     DISP "hit 'Continue-k5'."
968     BEEP
970     ON KEY 5 LABEL "Continue",Local_prty GOTO Calloads
972     LOOP
974     END LOOP
976 Calloads:OFF KEY
978     DISP " Calibration DATA for Cables, Couplers, Pads, etc. now LOADING "
980     !...................................................................
982     !Install new calibration files here!
984     !...................................................................
986     IF Printflag THEN PRINTER IS Printer
988     IF Printflag THEN PRINT "CALIBRATION DATA FOR THE FOLLOWING IS LOADED:"
990     !
992     !------------------------------------------------------------
994     !
996     Filename$="Cable6FT_1"&Sourcedisk$
998     CALL Enter_caldata(Filename$,Cable6_1(*),Cal_id$,C6_1pts)
1000    Baddata_id$(3)=Cal_id$
1002    IF Printflag THEN PRINT Cal_id$
1004    !
1006    Filename$="Cable6FT_6"&Sourcedisk$
1008    CALL Enter_caldata(Filename$,Cable6_6(*),Cal_id$,C6_6pts)
1010    Baddata_id$(4)=Cal_id$
1012    IF Printflag THEN PRINT Cal_id$
1014    !
1016    Filename$="Cable4FT_2"&Sourcedisk$
1018    CALL Enter_caldata(Filename$,Cable4_2(*),Cal_id$,C4_2pts)
1020    Baddata_id$(5)=Cal_id$
1022    IF Printflag THEN PRINT Cal_id$
1024    !
1026    Filename$="Cable4FT_4"&Sourcedisk$
1028    CALL Enter_caldata(Filename$,Cable4_4(*),Cal_id$,C4_4pts)
1030    Baddata_id$(6)=Cal_id$
1032    IF Printflag THEN PRINT Cal_id$
1034    !
1036    Filename$="Cable10F_3"&Sourcedisk$
1038    CALL Enter_caldata(Filename$,Cable10_3(*),Cal_id$,C10_3pts)
1040    Baddata_id$(7)=Cal_id$
1042    IF Printflag THEN PRINT Cal_id$
1044    !
1046    Filename$="Cable10F_5"&Sourcedisk$
1048    CALL Enter_caldata(Filename$,Cable10_5(*),Cal_id$,C10_5pts)
1050    Baddata_id$(8)=Cal_id$
1052    IF Printflag THEN PRINT Cal_id$
1054    !
1056    Filename$="Cable5FT_7"&Sourcedisk$
```

```
1058    CALL Enter_caldata(Filename$,Cable5_7(*),Cal_id$,C5_7pts)
1060    Baddata_id$(9)=Cal_id$
1062    IF Printflag THEN PRINT Cal_id$
1064    !
1066    Filename$="PAD_S6770"&Sourcedisk$
1068    CALL Enter_caldata(Filename$,Pad_s6770(*),Cal_id$,Pads_pts)
1070    Baddata_id$(10)=Cal_id$
1072    IF Printflag THEN PRINT Cal_id$
1074    !
1076    Filename$="PAD_5530"&Sourcedisk$
1078    CALL Enter_caldata(Filename$,Pad_f5530(*),Cal_id$,Padf_pts)
1080    Baddata_id$(11)=Cal_id$
1082    IF Printflag THEN PRINT Cal_id$
1084    !
1086    Filename$="PdAS6A1466"&Sourcedisk$
1088    CALL Enter_caldata(Filename$,Pad_as6a(*),Cal_id$,Pada_pts)
1090    Baddata_id$(12)=Cal_id$
1092    IF Printflag THEN PRINT Cal_id$
1094    !
1096    Filename$="ANZAC_JCT"&Sourcedisk$
1098    CALL Enter_caldata(Filename$,H_jct(*),Cal_id$,Jct_pts)
1100    Baddata_id$(13)=Cal_id$
1102    IF Printflag THEN PRINT Cal_id$
1104    !
1106    Filename$="Rcable4ft"&Sourcedisk$
1108    CALL Enter_caldata(Filename$,Cable_r4(*),Cal_id$,Cr4pts)
1110    Baddata_id$(14)=Cal_id$
1112    IF Printflag THEN PRINT Cal_id$
1114    !
1116    Filename$="Rcable12ft"&Sourcedisk$
1118    CALL Enter_caldata(Filename$,Cable_r12(*),Cal_id$,Cr12pts)
1120    Baddata_id$(15)=Cal_id$
1122    IF Printflag THEN PRINT Cal_id$
1124    !
1126    IF Printflag THEN
1128        PRINT RPT$("_",80)
1130        PRINT USING "4/"
1132    END IF
1134    DISP " Calibration DATA LOADED "
1136    WAIT 1
1138    PRINTER IS CRT
1140    CALL Wipe_clean
1142    RETURN
1144    !
1146    ! ////////////////////////////////////////////////////////////////
1148    !
1150 Fillcalibration:    ! Determine the cable, coupler and pad calibration
1152                     ! values for each frequency.
1154                     ! Save these in the adjust(*) file for use by the
1156                     ! measurement routine.
1158                     !
1160    IF Bug1 THEN
1162        PRINT TIME$(TIMEDATE);
1164        PRINT RPT$("<",15);" FILL CALIBRATION MATRIX ";RPT$(">",15)
1166    END IF
1168    DISP "NOW Filling Calibration matrix."
1170    ALLOCATE Adjust(Ftotal,Calib_items)
1172    Fcount=1
1174    FOR Frequency=Fstart TO Fstop STEP Fstep
1176        CALL Get_cal_value(Frequency,Coupinc,Coup_inc(*),Baddata,Inc_pts)
```

```
1178        IF Baddata THEN
1180            Cal_id$=Baddata_id$(1)
1182            GOSUB Flagbaddata
1184        END IF
1186        Adjust(Fcount,1)=Coupinc
1188        !
1190        CALL Get_cal_value(Frequency,Couprefl,Coup_refl(*),Baddata,Refl_pts)
1192        IF Baddata THEN
1194            Cal_id$=Baddata_id$(2)
1196            GOSUB Flagbaddata
1198        END IF
1200        Adjust(Fcount,2)=Couprefl
1202        !
1204        CALL Get_cal_value(Frequency,C6_1loss,Cable6_1(*),Baddata,C6_1pts)
1206        IF Baddata THEN
1208            Cal_id$=Baddata_id$(3)
1210            GOSUB Flagbaddata
1212        END IF
1214        Adjust(Fcount,3)=C6_1loss
1216        !
1218        CALL Get_cal_value(Frequency,C6_6loss,Cable6_6(*),Baddata,C6_6pts)
1220        IF Baddata THEN
1222            Cal_id$=Baddata_id$(4)
1224            GOSUB Flagbaddata
1226        END IF
1228        Adjust(Fcount,4)=C6_6loss
1230        !
1232        CALL Get_cal_value(Frequency,C4_2loss,Cable4_2(*),Baddata,C4_2pts)
1234        IF Baddata THEN
1236            Cal_id$=Baddata_id$(5)
1238            GOSUB Flagbaddata
1240        END IF
1242        Adjust(Fcount,5)=C4_2loss
1244        !
1246        CALL Get_cal_value(Frequency,C4_4loss,Cable4_4(*),Baddata,C4_4pts)
1248        IF Baddata THEN
1250            Cal_id$=Baddata_id$(6)
1252            GOSUB Flagbaddata
1254        END IF
1256        Adjust(Fcount,6)=C4_4loss
1258        !
1260        CALL Get_cal_value(Frequency,C10_3loss,Cable10_3(*),Baddata,C10_3pts)
1262        IF Baddata THEN
1264            Cal_id$=Baddata_id$(7)
1266            GOSUB Flagbaddata
1268        END IF
1270        Adjust(Fcount,7)=C10_3loss
1272        !
1274        CALL Get_cal_value(Frequency,C10_5loss,Cable10_5(*),Baddata,C10_5pts)
1276        IF Baddata THEN
1278            Cal_id$=Baddata_id$(8)
1280            GOSUB Flagbaddata
1282        END IF
1284        Adjust(Fcount,8)=C10_5loss
1286        !
1288        CALL Get_cal_value(Frequency,C5_7loss,Cable5_7(*),Baddata,C5_7pts)
1290        IF Baddata THEN
1292            Cal_id$=Baddata_id$(9)
1294            GOSUB Flagbaddata
1296        END IF
```

```
1298        Adjust(Fcount,9)=C5_7loss
1300        !
1302        CALL Get_cal_value(Frequency,Pads_loss,Pad_s6770(*),Baddata,Pads_pts)
1304        IF Baddata THEN
1306            Cal_id$=Baddata_id$(10)
1308            GOSUB Flagbaddata
1310        END IF
1312        Adjust(Fcount,10)=Pads_loss
1314        !
1316        CALL Get_cal_value(Frequency,Padf_loss,Pad_f5530(*),Baddata,Padf_pts)
1318        IF Baddata THEN
1320            Cal_id$=Baddata_id$(11)
1322            GOSUB Flagbaddata
1324        END IF
1326        Adjust(Fcount,11)=Padf_loss
1328        !
1330        CALL Get_cal_value(Frequency,Pada_loss,Pad_as6a(*),Baddata,Pada_pts)
1332        IF Baddata THEN
1334            Cal_id$=Baddata_id$(12)
1336            GOSUB Flagbaddata
1338        END IF
1340        Adjust(Fcount,12)=Pada_loss
1342        !
1344        CALL Get_cal_value(Frequency,Jct_loss,H_jct(*),Baddata,Jct_pts)
1346        IF Baddata THEN
1348            Cal_id$=Baddata_id$(13)
1350            GOSUB Flagbaddata
1352        END IF
1354        Adjust(Fcount,13)=Jct_loss
1356        !
1358        CALL Get_cal_value(Frequency,Cr4loss,Cable_r4(*),Baddata,Cr4pts)
1360        IF Baddata THEN
1362            Cal_id$=Baddata_id$(14)
1364            GOSUB Flagbaddata
1366        END IF
1368        Adjust(Fcount,14)=Cr4loss
1370        !
1372        CALL Get_cal_value(Frequency,Cr12loss,Cable_r12(*),Baddata,Cr12pts)
1374        IF Baddata THEN
1376            Cal_id$=Baddata_id$(15)
1378            GOSUB Flagbaddata
1380        END IF
1382        Adjust(Fcount,15)=Cr12loss
1384        !
1386        Fcount=Fcount+1
1388    NEXT Frequency
1390    DISP "NOW Tabulating calibration values."
1392    GOSUB Printcalvalues
1394    DISP CHR$(12)
1396    RETURN
1398    !
1400    ! ////////////****FLAG BAD DATA****//////////////////////////
1402    !
1404 Flagbaddata:      !Inform the operator that there is wrong data
1406                   !being brought back from Enter_cal_data
1408                   !
1410    PRINTER IS Printer
1412    PRINT RPT$("*",5);" NO CAL DATA at ";Frequency;
1414    PRINT " MHz: ";Cal_id$
1416    BEEP
```

```
1418   PRINTER IS CRT
1420   RETURN
1422   !
1424   ! ////////////////////////////////////////////////////////////////////
1426   !
1428 Printcalvalues:     !MAKE LIST OF CALIBRATION VALUES USED.
1430                     !
1432   PRINTER IS Printer
1434   PRINT
1436   PRINT RPT$("*",24);" CALIBRATION / LOSS VALUES (dB) ";RPT$("*",24)
1438   PRINT
1440   !
1442   !............first half of the values...............
1444   !
1446   PRINT "Frequency   Coupler       --------------- BLUE CABLES -------";
1448   PRINT "-------------"
1450   PRINT "   MHz     Fward   Refl    6ft#1  6ft#6  4ft#2  4ft#4 10ft#3 ";
1452   PRINT "10ft#5  5ft#7"
1454 Lossfmt1:IMAGE M5D.D,X,2(MDD.DD,X),X,2(MDD.DD,X),#
1456 Lossfmt2:IMAGE 5(MDD.DD,X)
1458   Fcount=1
1460   FOR Frequency=Fstart TO Fstop STEP Fstep
1462       Coupinc=10*LGT(Adjust(Fcount,1))            !Coupler incident
1464       Couprefl=10*LGT(Adjust(Fcount,2))           !Coupler reflected
1466       C6_1loss=10*LGT(Adjust(Fcount,3))           !6 foot BLUE cable #1
1468       C6_6loss=10*LGT(Adjust(Fcount,4))           !6 foot BLUE cable #6
1470       C4_2loss=10*LGT(Adjust(Fcount,5))           !4 foot BLUE cable #2
1472       C4_4loss=10*LGT(Adjust(Fcount,6))           !4 foot BLUE cable #4
1474       C10_3loss=10*LGT(Adjust(Fcount,7))          !10 foot BLUE cable #3
1476       C10_5loss=10*LGT(Adjust(Fcount,8))          !10 foot BLUE cable #5
1478       C5_7loss=10*LGT(Adjust(Fcount,9))           !4 foot BLUE cable #4
1480       PRINT USING Lossfmt1;Frequency,Coupinc,Couprefl,C6_1loss,C6_6loss
1482       PRINT USING Lossfmt2;C4_2loss,C4_4loss,C10_3loss,C10_5loss,C5_7loss
1484       Fcount=Fcount+1
1486   NEXT Frequency
1488   PRINT RPT$("-",80)
1490   PRINT
1492   !
1494   !.............last half of the values...............
1496   !
1498   PRINT "Frequency S6770  F5530   ASA6A   HJct    Semi-Rigid"
1500   PRINT "   MHz        pad     pad      pad   loss    4ft   12ft"
1502 Lossfmt3:IMAGE M5D.D,X,2(MDD.DD,X),X,MDD.DD,X,#
1504 Lossfmt4:IMAGE 3(MDD.DD,X)
1506   Fcount=1
1508   FOR Frequency=Fstart TO Fstop STEP Fstep
1510       Pads_loss=10*LGT(Adjust(Fcount,10))        !Weinschel S6770 10dB pad
1512       Padf_loss=10*LGT(Adjust(Fcount,11))        !Weinschel F5530 10dB pad
1514       Pada_loss=10*LGT(Adjust(Fcount,12))        !Weinschel AS6A-1466 10dB
1516       Jct_loss=10*LGT(Adjust(Fcount,13))         !Anzac Hybrid Junction
1518       Cr4loss=10*LGT(Adjust(Fcount,14))         ! 4ft Rigid coax
1520       Cr12loss=10*LGT(Adjust(Fcount,15))        ! 12ft Rigid coax
1522       PRINT USING Lossfmt3;Frequency,Pads_loss,Padf_loss,Pada_loss
1524       PRINT USING Lossfmt4;Jct_loss,Cr4loss,Cr12loss
1526       Fcount=Fcount+1
1528   NEXT Frequency
1530   PRINT RPT$("*",80)
1532   PRINT
1534   PRINTER IS CRT
1536   RETURN
```

```
1538   !
1540   ! ///////////////////////////////////////////////////////////////////
1542   !
1544 Extract_caldata:    !Get all calibration data for this
1546                     !frequency.
1548   !
1550   ! Calibration data for all cables, probes, & power heads.
1552   !
1554   Pwrmtrcal1=FNPwrmtrcal1((Frequency))          !18 GHz HEAD.
1556   Pwrmtrcal2=FNPwrmtrcal2((Frequency))          !26 GHz HEAD.
1558   !
1560   Coupinc=Adjust(Fcount,1)                     !Coupler incident
1562   Coupref1=Adjust(Fcount,2)                    !Coupler reflected
1564   C6_1loss=Adjust(Fcount,3)                    !6 foot BLUE cable #1
1566   C6_6loss=Adjust(Fcount,4)                    !6 foot BLUE cable #6 rcvr.
1568   C4_2loss=Adjust(Fcount,5)                    !4 foot BLUE cable #2
1570   C4_4loss=Adjust(Fcount,6)                    !4 foot BLUE cable #4
1572   C10_3loss=Adjust(Fcount,7)                   !10 foot BLUE cable #3
1574   C10_5loss=Adjust(Fcount,8)                   !10 foot BLUE cable #5
1576   C5_7loss=Adjust(Fcount,9)                    !5 foot BLUE cable #7
1578   Pads_loss=Adjust(Fcount,10)                  !Weinschel S6770 10dB pad
1580   Padf_loss=Adjust(Fcount,11)                  !Weinschel F5530 10dB pad
1582   Pada_loss=Adjust(Fcount,12)                  !Weinschel AS6A-1466 10dB
1584   Jct_loss=Adjust(Fcount,13)                   !Anzac Hybrid Junction
1586   Cr4loss=Adjust(Fcount,14)                   !4ft Semi-rigid coax lines
1588   Cr12loss=Adjust(Fcount,15)                  !12ft Semi-rigid coax lines
1590   RETURN
1592   !
1594   ! ///////////////////////////////////////////////////////////////////
1596   !
1598 Flip_printflag:  !
1600   DISP " Toggle PRINTING of measurement data. "
1602   Waittime=TIMEDATE
1604   LOOP
1606       IF Printflag2 THEN
1608           ON KEY 0 LABEL "Print is ON",Local_prty GOSUB Toggleprint
1610       ELSE
1612           ON KEY 0 LABEL "Print is OFF",Local_prty GOSUB Toggleprint
1614       END IF
1616   EXIT IF TIMEDATE-Waittime>4
1618   END LOOP
1620   DISP CHR$(12)
1622   OFF KEY
1624   RETURN
1626   ! ..........................
1628 Toggleprint:!
1630   IF Printflag2 THEN
1632       Printflag2=0
1634   ELSE
1636       Printflag2=1
1638   END IF
1640   RETURN
1642   !
1644   !//////////////////////****PERFORM MEASUREMENTS****///////////////
1646   !
1648 Do_measurements:!
1650   !
1652   IF Bug1 THEN
1654       PRINT TIME$(TIMEDATE);RPT$("<",20);" DO MEASUREMENTS ";RPT$(">",20)
1656   END IF
```

```
1658   ! ...................Initialize instruments ....................
1660   REMOTE @Sig_gen
1662   IF Fp436a1 OR Fp436a2 THEN CALL Menu_pwr436a ! Set up 436A pwr mtrs
1664   IF Fv3456a1 THEN CALL Setdvm_3456a(@Dvm1)
1666   IF Fv3456a2 THEN CALL Setdvm_3456a(@Dvm2)
1668   IF Fv3478a1 THEN CALL Setdvm_3478a(@Dvm3)
1670   IF Fsa8566b THEN CALL Spec_alzr_setup(@Spec_alzr)
1672   IF Test_type$<>"OTHER (NO STEPS)" THEN
1674       CALL Initializemotor(@Motor)
1676       CALL Zeromotor(@Motor)
1678   END IF
1680   IF Test_type$="MODE TUNE EMISSIONS" THEN
1682       CALL Set_dbm(-140,0,@Sig_gen)        !EUT is the source
1684   END IF
1686   ! ..............................................................
1688   !
1690   Column=1
1692   Beginstep=Begin_step
1694   Steps=Begin_step-1
1696   REPEAT   ! measurements for all steps or once for non-stepping type.
1698       Steps=Steps+1
1700       !
1702       IF (Steps-1)/40.=INT((Steps-1)/40.) OR Steps=Begin_step THEN
1704           IF Test_type$="MODE TUNE EMISSIONS" THEN
1706               GOSUB Flip_printflag  ! includes WAIT action.
1708           ELSE
1710               GOSUB Read_zero_field ! for all enabled instruments.
1712           END IF
1714       ELSE
1716           GOSUB Flip_printflag
1718       END IF
1720       !
1722       ! ............... ZERO Readings or WAIT complete ...........
1724       !
1726       IF Total_chans<1 THEN ! Print single header for all frequencies
1728           IF Printflag AND Printflag2 THEN GOSUB Print_headinfo
1730       END IF
1732       IF Test_type$<>"MODE TUNE EMISSIONS" THEN ! Restore power
1734           CALL Set_freq((Frequency),@Sig_gen)
1736           CALL Set_dbm(Dbm,1,@Sig_gen)
1738       END IF
1740       !
1742       ! ...............Measure all frequencies ...................
1744       !
1746       Fcount=1
1748       FOR Frequency=Fstart TO Fstop STEP Fstep
1750           DISP CHR$(129)
1752           DISP " TIME: ";TIME$(TIMEDATE);
1754           IF Test_type$="OTHER (NO STEPS)" THEN
1756               DISP " Now Testing: FREQUENCY =";Frequency;" MHz. "
1758           ELSE
1760               DISP "  TUNER STEP ";Steps;", FREQUENCY =";Frequency;" MHz. "
1762           END IF
1764           GOSUB Extract_caldata    ! Get all calibration data for this
1766                                    ! frequency.
1768           Rawdata(1,Column)=Frequency
1770           IF Test_type$<>"MODE TUNE EMISSIONS" THEN
1772               CALL Set_freq((Frequency),@Sig_gen)
1774           END IF
1776           IF Search_eut THEN GOSUB Level_eut_out
```

```
1778            IF Search_pwr THEN GOSUB Level_net_input
1780            GOSUB Read_meters        ! Read all enabled instruments.
1782                                     ! See Configure_instr for changes.
1784                                     ! Calibration data is applied there
1786                                     ! via Apply_cal_data.
1788            !
1790            ! ...............FILL the DATA file ...................
1792            !
1794 Fill_data_file: ! **** Make sure this assignment matches defns.
1796            SELECT Test_type$
1798            CASE "MODE TUNE REGULAR"
1800               Rawdata(2,Column)=P1
1802               Rawdata(3,Column)=P2
1804               Rawdata(4,Column)=Sa_pwr
1806            CASE "MODE TUNE EMISSIONS"
1808               Rawdata(1,Column)=Sa_pwr
1810            CASE "OTHER (NO STEPS)"
1812               Rawdata(2,Column)=P1
1814               Rawdata(3,Column)=P2
1816               Rawdata(4,Column)=V1
1818            END SELECT
1820            !
1822            IF Total_chans>0 THEN
1824               FOR P=Total_meters+2 TO Total_chans+Total_meters+1
1826                  Rawdata(P,Column)=Probe_v_m(P-Total_meters-1)
1828               NEXT P
1830            END IF
1832            !.....................................................
1834            IF Printflag AND Printflag2 THEN
1836               IF Total_chans>0 THEN GOSUB Print_headinfo
1838               GOSUB Printrawdata
1840            END IF
1842            Column=Column+1
1844            Fcount=Fcount+1
1846         NEXT Frequency
1848         !
1850         ! ............... ALL frequencies measured .................
1852         !
1854         IF Test_type$="OTHER (NO STEPS)" THEN
1856            GOSUB Save_data
1858         ELSE
1860            PRINT TIME$(TIMEDATE);" ...Step number";Steps;" completed....."
1862            IF (Column+Ftotal-1>File20steps) OR (Steps=Tuner_steps) THEN
1864               Endstep=Steps
1866               GOSUB Save_data
1868               Beginstep=Endstep+1
1870               Column=1
1872               MAT Rawdata= Rawdata*(0.)
1874            END IF
1876            CALL Movemotor(@Motor)
1878         END IF
1880      UNTIL Steps>=Tuner_steps OR Test_type$="OTHER (NO STEPS)"
1882      !
1884      IF Test_type$<>"MODE TUNE EMISSIONS" THEN
1886         CALL Set_dbm(-140,0,@Sig_gen)
1888      END IF
1890      LOCAL 7
1892      RETURN  ! ALL Measurements complete.
1894      !
1896      ! ////////////////////////////////////////////////////////////////
```

```
1898   !
1900 Read_zero_field:  !
1902   PRINT TIME$(TIMEDATE);"  Step number";Steps;", zero meters."
1904   !
1906   ! ............. Measure all zero field values .............
1908   !
1910   CALL Set_dbm(-140,0,@Sig_gen)
1912   IF Fp436a1 AND Fp436a2 THEN
1914       CALL Zero_pwr_mtrs(@Sig_gen,@Pwr1,@Pwr2)
1916   ELSE
1918       IF Fp436a1 THEN CALL Zero_pwr_mtrs(@Sig_gen,@Pwr1)
1920       IF Fp436a2 THEN CALL Zero_pwr_mtrs(@Sig_gen,@Pwr2)
1922   END IF
1924   IF Fp438a1 THEN
1926       Ab$="AB"
1928       CALL Zero_438a(@Dual_pwr1,Ab$)
1930   END IF
1932   IF Fp438a2 THEN
1934       Ab$="A"
1936       CALL Zero_438a(@Dual_pwr2,Ab$)
1938   END IF
1940   IF Fv3456a1 THEN CALL Readdvm(Z3456a1,@Dvm1)
1942   IF Fv3456a2 THEN CALL Readdvm(Z3456a2,@Dvm2)
1944   IF Fv3478a1 THEN CALL Readdvm(Z3478a1,@Dvm3)
1946   IF Bug1 THEN
1948       PRINTER IS Printer
1950       PRINT "Zeros DVM1=";Z3456a1;", DVM2=";Z3456a2;" DVM3=";Z3478a1
1952       PRINTER IS CRT
1954   END IF
1956   !
1958   ! Fill Probe_volts(30) using Probe_addr(*) and Total_chans
1960   !
1962   IF Total_chans>0 THEN
1964       MAT Probe_zero= (0)
1966       CALL Read_probes(@Gpio)
1968       MAT Probe_zero= Probe_volts
1970       IF MAX(Probe_zero(*))>10 OR MIN(Probe_zero(*))<-10 THEN
1972           PRINT TIME$(TIMEDATE);" ... ";
1974           PRINT " WARNING ... Check Multiprobe zero ******** "
1976       END IF
1978   END IF
1980   RETURN
1982   !
1984   ! ///////////// APPLY CALIBRATION TO MEASUREMENT DATA ////////
1986   !
1988 Apply_cal_data:! For listing of valid variable names
1990                ! see Extract_caldata.  Values are in ratio form.
1992 Cal_power_1_2:!
1994   P1=Power1*Coupinc*Pwrmtrcal1*Padf_loss/(C10_3loss*Pads_loss)
1996   P2=Power2*Coupref1*Pwrmtrcal1*C10_3loss*Pads_loss
1998   RETURN
2000   !-----------------------------------------
2002 Cal_power_3_4:!
2004   P3=Power3
2006   P4=Power4
2008   RETURN
2010   !-----------------------------------------
2012 Cal_power_5:!
2014   P5=Power5
2016   RETURN
```

```
2018   !-----------------------------------------
2020 Cal_power_6:!
2022   P6=Power6
2024   RETURN
2026   !-----------------------------------------
2028 Cal_sa_power:!
2030   Sa_pwr=Sa_power*C10_5loss*C4_2loss*C4_4loss
2032   RETURN
2034   !-----------------------------------------
2036   !
2038   ! /////////////////////////////////////////////////////////////////
2040   !
2042 Read_meters:! Control module for all instrument reads.
2044   Too_hot=0
2046   P1=0
2048   P2=0
2050   Checktime=TIMEDATE
2052   !-----------------------------------------
2054 Hp438a_1:!
2056   IF Fp438a1 THEN
2058       GOSUB Power_1_2    ! HP438A both channels
2060                          ! returns Power1, Power2 (watts)
2062       IF Too_hot THEN GOTO Read_meters
2064       GOSUB Cal_power_1_2! correct for losses and return P1,P2
2066 Min_power:IF (P1-P2)<Min_pwr THEN
2068           BEEP
2070           PRINTER IS Printer
2072           PRINT TIME$(TIMEDATE);" "
2074           PRINT RPT$("-",40);" INPUT IS TOO LOW ! "
2076           PRINT "Raw P1=";Power1;" ** Cal P1=";P1
2078           PRINT "Raw P2=";Power2;" ** Cal P2=";P2
2080           PRINT "Net input power (P1-P2) =";P1-P2
2082           PRINT RPT$("-",40)
2084           PRINTER IS CRT
2086           GOSUB Adjust_power
2088           GOTO Read_meters
2090       END IF
2092   END IF
2094   !-----------------------------------------
2096 Hp438a_2:!
2098   IF Fp438a2 THEN
2100       GOSUB Power_3_4   ! Set for channel A (Power3) only, Power4=0
2102                         ! returns Power3, Power4 (watts)
2104       IF Too_hot THEN GOTO Read_meters
2106       GOSUB Cal_power_3_4 ! correct for losses and return P3,P4
2108   END IF
2110   !-----------------------------------------
2112 Hp436a_1:!
2114   IF Fp436a1 THEN
2116       GOSUB Power_5   ! HP 436A
2118                       ! returns Power5
2120       IF Too_hot THEN GOTO Read_meters
2122       GOSUB Cal_power_5   ! correct for losses and return P5
2124   END IF
2126   !-----------------------------------------
2128 Hp436a_2:!
2130   IF Fp436a2 THEN
2132       GOSUB Power_6   ! HP 436A
2134                       ! returns Power6
2136       IF Too_hot THEN GOTO Read_meters
```

```
2138       GOSUB Cal_power_6    ! correct for losses and return P6
2140    END IF
2142    !-------------------------------------------
2144 Nbs_probes:!
2146    IF Total_chans>0 THEN GOSUB Probe_rd      ! Multiprobe system
2148    IF Too_hot THEN GOTO Read_meters          ! returns corrected V/m.
2150    !-------------------------------------------
2152 Wait_loop:!
2154    LOOP
2156    EXIT IF (TIMEDATE-Checktime)>Time_eut
2158    END LOOP
2160    !-------------------------------------------
2162 Hp3456a_1:! =======  EUT connected to this dvm. =========
2164    IF Fv3456a1 THEN
2166       CALL Readdvm(Volt1,@Dvm1)    ! HP digital voltmeter
2168                                    ! returns Volts (DC volts)
2170       V1=Volt1-Z3456a1             ! correct for zero, yields V1
2172       IF V1>Max_eut THEN
2174          PRINTER IS Printer
2176          PRINT TIME$(TIMEDATE);"...DVM1 error / EUT overload. "
2178          PRINT "Set max=";Max_eut;", Reading=";Volt1;", Zero=";Z3456a1;
2180          PRINT ", Adjusted reading=";V1
2182          PRINTER IS CRT
2184          GOSUB Reduce_power
2186          GOTO Read_meters
2188       END IF
2190    END IF
2192    !-------------------------------------------
2194 Hp3456a_2:!
2196    IF Fv3456a2 THEN
2198       CALL Readdvm(Volt2,@Dvm2)    ! HP digital voltmeter
2200                                    ! returns Volts (DC volts)
2202       V2=Volt2-Z3456a2             ! correct for zero, yields V2
2204    END IF
2206    !-------------------------------------------
2208 Hp3478a_1:!
2210    IF Fv3478a1 THEN
2212       CALL Readdvm(Volt3,@Dvm3)    ! HP digital voltmeter
2214                                    ! returns Volts (DC volts)
2216       V3=Volt3-Z3478a1             ! correct for zero, yields V3
2218    END IF
2220    !-------------------------------------------
2222 Hp59306a_relay:! An example of using the relay to measure multiple
2224                ! quantities.  This requires additional instrument to
2226                ! actually do the measurements, as the relay only controls
2228                ! a system of rf switches.
2230                ! In this example, turn off the Spectrum Analyzer flag.
2232    IF Fr59306a THEN
2234       OUTPUT @Rly1;"A123"     ! Toggle to SUM port
2236       CALL Spec_alzr_start(Frequency,@Spec_alzr)
2238       CALL Spec_alzr_read(Sa_power,Frequency,@Spec_alzr)
2240       Sa_power=10.0^((Sa_power/10.0)-3.0) ! dBm -> watts
2242       GOSUB Cal_sa_power! correct for losses and return Sa_pwr
2244       Sum_power=Sa_pwr
2246       !
2248       OUTPUT @Rly1;"B123"     ! Toggle to DIFFERENCE port
2250       CALL Spec_alzr_start(Frequency,@Spec_alzr)
2252       CALL Spec_alzr_read(Sa_power,Frequency,@Spec_alzr)
2254       Sa_power=10.0^((Sa_power/10.0)-3.0) ! dBm -> watts
2256       GOSUB Cal_sa_power! correct for losses and return Sa_pwr
```

```
2258        Diff_power=Sa_pwr
2260    END IF
2262    !-----------------------------------------------
2264 Spec_alzr:!
2266    IF Fsa8566b AND NOT Fr59306a THEN  ! HP8566B Spectrum analyzer
2268        CALL Spec_alzr_start(Frequency,@Spec_alzr)
2270        CALL Spec_alzr_read(Sa_power,Frequency,@Spec_alzr)
2272        Sa_power=10.0^((Sa_power/10.0)-3.0) ! dBm -> watts
2274        GOSUB Cal_sa_power! correct for losses and return Sa_pwr
2276    END IF
2278    RETURN
2280    !
2282    ! //////////// Read instrument subroutines //////////////////
2284    !
2286    ! ............ HP 438A Dual power meter - @Dual_pwr1 .........
2288    !
2290 Power_1_2:Ab$="AB"
2292    CALL Read_dual_pwr(Ab$,Apower,Bpower,Too_hot,Valid,@Dual_pwr1)
2294    IF Too_hot THEN
2296        GOSUB Reduce_power
2298        RETURN
2300    END IF
2302    IF NOT Valid AND NOT Too_hot THEN
2304        GOSUB Dual_pwr_error
2306        GOTO Power_1_2          ! Repeat measurements
2308    END IF
2310    IF Ab$="AB" OR Ab$="A" THEN
2312        IF Apower<0. THEN Apower=0.        ! Power detectors are not sources
2314        Power1=Apower
2316    END IF
2318    IF Ab$="AB" OR Ab$="B" THEN
2320        IF Bpower<0. THEN Bpower=0.
2322        Power2=Bpower
2324    END IF
2326    RETURN
2328    !
2330    ! ............ HP 438A Dual power meter - @Dual_pwr2 .........
2332    !
2334 Power_3_4:Ab$="A"    ! or Ab$="AB" if you want both channels.
2336    CALL Read_dual_pwr(Ab$,Apower,Bpower,Too_hot,Valid,@Dual_pwr2)
2338    IF Too_hot THEN
2340        GOSUB Reduce_power
2342        RETURN
2344    END IF
2346    IF NOT Valid AND NOT Too_hot THEN
2348        GOSUB Dual_pwr_error
2350        GOTO Power_3_4          ! Repeat measurements
2352    END IF
2354    IF Ab$="AB" OR Ab$="A" THEN
2356        IF Apower<0. THEN Apower=0.        ! Power detectors are not sources
2358        Power3=Apower
2360    END IF
2362    IF Ab$="AB" OR Ab$="B" THEN
2364        IF Bpower<0. THEN Bpower=0.
2366        Power4=Bpower
2368    END IF
2370    RETURN
2372    !
2374    ! .................. HP 436A Power meter - @Pwr1 ............
2376    !
```

```
2378 Power_5: ! Pwr_id$="P1"
2380   CALL Read_pwr_meter(Power,Pwr_id$,Valid,@Pwr1,@Sig_gen)
2382   IF NOT Valid THEN
2384       DISP "ERROR IN 436a POWER METER 1"
2386       BEEP
2388       PAUSE
2390       Power=0.
2392       Too_hot=1
2394   END IF
2396   IF Power<0. THEN Power=0.
2398   Power5=Power
2400   RETURN
2402   !
2404   ! .................. HP 436A Power meter - @Pwr2 ............
2406   !
2408 Power_6: ! Pwr_id$="P6"
2410   CALL Read_pwr_meter(Power,Pwr_id$,Valid,@Pwr2,@Sig_gen)
2412   IF NOT Valid THEN
2414       DISP "ERROR IN 436a POWER METER 2"
2416       BEEP
2418       PAUSE
2420       Power=0.
2422       Too_hot=1
2424   END IF
2426   IF Power<0. THEN Power=0.
2428   Power6=Power
2430   RETURN
2432   !
2434   ! .................. NBS Multiprobe system ..................
2436   !
2438 Probe_rd:!
2440   IF Total_chans>0 THEN
2442       CALL Read_probes(@Gpio)
2444       Too_hot=0
2446       FOR P=1 TO Total_chans
2448           Too_hot=Too_hot OR Overrange(P)
2450       NEXT P
2452       IF Too_hot THEN
2454           GOSUB Reduce_power
2456       ELSE
2458           CALL Apply_probe_cal(Frequency)    ! Amplitude correction.
2460                                              ! Frequency correction.
2462       END IF
2464   END IF
2466   RETURN
2468   !
2470   ! ///////////////////////////////////////////////////////////////
2472   !
2474 Level_eut_out:! This routine will adjust the signal generator
2476               ! output to cause the EUT output (tied to @Dvm1)
2478               ! to fall within the limits of Min_eut and Max_eut.
2480               ! All the while within the bounds of Low_dbm to High_dbm.
2482   !
2484   !
2486   !
2488   !
2490   !
2492   RETURN
2494   !
2496   ! ///////////////////////////////////////////////////////////////
```

```
2498   !
2500 Level_net_input:! This routine will adjust the signal generator
2502                  ! output to cause the corrected net input power
2504                  ! to fall within the limits of Min_pwr and Max_pwr
2506                  ! All the while within the bounds of Low_dbm to High_dbm.
2508   !
2510   !
2512   !
2514   !
2516   !
2518   RETURN
2520   !
2522   ! ///////////////////////////////////////////////////////////////////
2524   !
2526 Adjust_power:  !
2528   DISP " INPUT power is too low. Check system (Continue-k5) "
2530   ON KEY 5 LABEL "Continue",Local_prty GOTO Tryitagain
2532   ON KEY 0 LABEL "Reduce Power",Local_prty GOSUB Reduce_power
2534   ON KEY 2 LABEL "Increase Pwr",Local_prty GOSUB Increase_pwr
2536   LOOP
2538 Myself:ON KEY 6 LABEL " dBm="&VAL$(Dbm),Local_prty GOTO Myself
2540   END LOOP
2542 Tryitagain:OFF KEY
2544   DISP CHR$(12)
2546   RETURN
2548   ! ..........................................................
2550 Reduce_power:!
2552   Dbm=Dbm-1
2554   CALL Set_dbm(Dbm,1,@Sig_gen)
2556   IF Printflag THEN
2558       PRINTER IS Printer
2560       PRINT TIME$(TIMEDATE);": Step#";Steps;" Freq=";Frequency;
2562       PRINT RPT$("*",10);" NEW GENERATOR LEVEL =";Dbm
2564       PRINTER IS CRT
2566   END IF
2568   RETURN
2570   ! ..........................................................
2572 Increase_pwr:!
2574   Dbm=Dbm+1
2576   CALL Set_dbm(Dbm,1,@Sig_gen)
2578   IF Printflag THEN
2580       PRINTER IS Printer
2582       PRINT TIME$(TIMEDATE);": Step#";Steps;" Freq=";Frequency;
2584       PRINT RPT$("*",10);" NEW GENERATOR LEVEL =";Dbm
2586       PRINTER IS CRT
2588   END IF
2590   RETURN
2592   !
2594   ! ///////////////////////////////////////////////////////////////////
2596   !
2598 Dual_pwr_error:!
2600   CALL Set_dbm(-140,0,@Sig_gen)     ! Kill power
2602   IF Printflag THEN
2604       PRINTER IS Printer
2606       PRINT TIME$(TIMEDATE);": Step#";Steps;" Freq=";Frequency;
2608       PRINT RPT$("*",10);" ERROR IN DUAL POWER METER !!!"
2610       PRINTER IS CRT
2612   END IF
2614   DISP " ERROR in DUAL POWER METER, correct and 'CONTINUE' "
2616   BEEP
```

```
2618   PAUSE
2620   CALL Set_dbm(Dbm,1,@Sig_gen)      ! Restore power.
2622   RETURN
2624   !
2626   ! ////////////****PRINT HEADING FOR RAW DATA****/////////////
2628   !
2630 Print_headinfo: ! Values in order of insertion into matrix.
2632   PRINTER IS Printer
2634   PRINT
2636   SELECT Test_type$
2638   CASE "MODE TUNE REGULAR"
2640       PRINT RPT$("-",15);"Identifier: ";Run_id$;
2642       PRINT " STEP NUMBER ";Steps;RPT$("-",15)
2644       PRINT "FREQUENCY   INC-PWR   REFL-PWR ";
2646       PRINT "   REC-PWR"
2648       PRINT "   MHz         Watts       Watts  ";
2650       PRINT "    Watts"
2652   CASE "MODE TUNE EMISSIONS"
2654       PRINT RPT$("-",15);"Identifier: ";Run_id$;
2656       PRINT " STEP NUMBER ";Steps;RPT$("-",15)
2658       PRINT "FREQUENCY   REC-PWR "
2660       PRINT "   MHz         Watts   "
2662   CASE "OTHER (NO STEPS)"
2664       PRINT RPT$("=",80)
2666       PRINT "Measurement Identifier:  ";Run_id$
2668       PRINT Measmt_id$
2670       PRINT RPT$(".",80)
2672       PRINT
2674       PRINT "FREQUENCY   INC-PWR   REFL-PWR ";
2676       PRINT "   Probe OUTPUT"
2678       PRINT "   MHz         Watts       Watts  ";
2680       PRINT "    Volts"
2682   END SELECT
2684   PRINTER IS CRT
2686   RETURN
2688   !
2690   ! ////////////////****PRINT RAW DATA****/////////////////////
2692   !
2694 Printrawdata:!
2696 Rawimage1:IMAGE 6D.2D,X,#
2698 Rawimage2:IMAGE #,MD.DDDE,X
2700   PRINTER IS Printer
2702   PRINT USING Rawimage1;Rawdata(1,Column)
2704   FOR I=2 TO Total_meters+1
2706       PRINT USING Rawimage2;Rawdata(I,Column)
2708   NEXT I
2710   PRINT
2712   IF Total_chans>1 THEN GOSUB Print_probes
2714   PRINTER IS CRT
2716   RETURN
2718   !
2720   ! ///////////////////////////////////////////////////////////
2722   !
2724 Print_probes:!
2726   PRINT RPT$("_",80)
2728   PRINT "Amp# Probe# Axis  Zero  Output Orng?";
2730   PRINT "     Volts/mtr"
2732 Pimage1:IMAGE M3D,2X,M3D,3X,A,3X,2(M4D,2X),MDD,2X,M4D.2D
2734   FOR I=1 TO Total_chans
2736       Amp=Probe_addr(I,1)
```

```
2738         Probe=Probe_addr(I,2)
2740         SELECT Probe_addr(I,3)
2742         CASE 1
2744             Ax$="X"
2746         CASE 2
2748             Ax$="Y"
2750         CASE 3
2752             Ax$="Z"
2754         CASE 4
2756             Ax$="S"
2758         CASE ELSE
2760             Ax$="E"
2762         END SELECT
2764         Org=Overrange(I)
2766         Zer=Probe_zero(I)
2768         A_d=Probe_volts(I)
2770         V_m=Rawdata(Total_meters+I+1,Column)
2772         PRINT USING Pimage1;Amp,Probe,Ax$,Zer,A_d,Org,V_m
2774     NEXT I
2776     PRINT RPT$("_",80)
2778     PRINT
2780     PRINT
2782     RETURN
2784     !
2786     !/////////////////////****SAVE DATA****////////////////////////
2788     !
2790 Save_data:!
2792     ON ERROR CALL Errortrap
2794     IF Test_type$="OTHER (NO STEPS)" THEN
2796         Filename$=Run_id$
2798     ELSE
2800         Filename$="S"&VAL$(Beginstep)&"_"&VAL$(Endstep)
2802     END IF
2804     Filename$=Filename$&Outdisk$
2806     Filesize=INT(((Total_chans+Total_meters+1)*File20steps*8)/256)+2
2808     CREATE BDAT Filename$,Filesize,256
2810     ASSIGN @Datapath TO Filename$
2812     OUTPUT @Datapath;Rawdata(*)
2814     ASSIGN @Datapath TO *
2816     PRINTER IS Printer
2818     IF Test_type$="OTHER (NO STEPS)" THEN
2820         PRINT TIME$(TIMEDATE);" ..... DATA STORED ON FILE ";Filename$
2822     ELSE
2824         Filename$="S"&VAL$(Beginstep)&"_"&VAL$(Endstep)
2826         PRINT TIME$(TIMEDATE);"............DATA FOR STEPS ";
2828         PRINT Beginstep;" TO ";Endstep;" STORED ON FILE ";Filename$
2830     END IF
2832     OFF ERROR
2834     PRINTER IS CRT
2836     RETURN
2838     !
2840     ! ///////////////////**** SAVE CONFIGURE ****//////////////////
2842     !
2844 Save_configure:!
2846     ON ERROR CALL Errortrap
2848     Filename$="CONFIGURE"
2850     Filename$=Filename$&Outdisk$
2852     CREATE BDAT Filename$,16,256
2854     ASSIGN @Datapath TO Filename$
2856     OUTPUT @Datapath;Run_id$
```

```
2858    OUTPUT @Datapath;Measmt_id$
2860    OUTPUT @Datapath;Time_date$
2862    OUTPUT @Datapath;Fstart,Fstop,Fstep
2864    IF Test_type$="OTHER (NO STEPS)" THEN
2866        OUTPUT @Datapath;1
2868    ELSE
2870        OUTPUT @Datapath;Total_steps
2872    END IF
2874    OUTPUT @Datapath;Total_meters
2876    OUTPUT @Datapath;Total_chans
2878    OUTPUT @Datapath;Probe_addr(*)
2880    OUTPUT @Datapath;Meter_defns$(*)
2882    OUTPUT @Datapath;File20steps
2884    ASSIGN @Datapath TO *
2886    OFF ERROR
2888    PRINTER IS CRT
2890    PRINT TIME$(TIMEDATE);"  CONFIGURE file for ";Run_id$;" SAVED."
2892    RETURN
2894    !
2896    ! ////////////////////////////////////////////////////////////////
2898    !
2900 Print_vitals: !
2902    PRINTER IS Printer
2904    PRINT RPT$("_",80)
2906    PRINT "THIS DATA SET IS IDENTIFIED AS:  ";Run_id$
2908    PRINT "MEASUREMENT date:  ";Time_date$
2910    PRINT RPT$("-",80)
2912    PRINT Measmt_id$
2914    PRINT RPT$("-",80)
2916    PRINT "FREQUENCIES ";Fstart;" TO ";
2918    PRINT Fstop;" STEP ";Fstep;" MHz."
2920    PRINT "THE TUNER STEPPED ";Total_steps;" increments."
2922    PRINT Total_meters;" PWR METERS and DVMs, along with ";Total_chans;
2924    PRINT " channels of the NBS multiprobe system."
2926    PRINT
2928    PRINT "The measured DATA are defined as follows:"
2930    PRINT RPT$("-",80)
2932    PRINT "Data slot #    Description";
2934    PRINT TAB(40);"Data slot #   Description"
2936    J=INT(((Total_chans+Total_meters)/2)+1)
2938    IF J<>((Total_chans+Total_meters)/2)+1 THEN J=J+1
2940    I=1
2942    K=J         ! J is starting point of second column.
2944    REPEAT
2946        PRINT I;": ";Meter_defns$(I);
2948        IF K<=Total_chans+Total_meters THEN
2950            PRINT TAB(40);K;": ";Meter_defns$(K)
2952        ELSE
2954            PRINT
2956        END IF
2958        I=I+1
2960        K=K+1
2962    UNTIL I>=J
2964    PRINT RPT$("-",80)
2966    PRINT USING "2/"
2968    PRINTER IS CRT
2970    RETURN
2972    !
2974    ! ////////////////////////////////////////////////////////////////
2976    !
```

```
2978   END
2980   !
2982   ! ****************************************************************
2984   !
2986   SUB Measure_menu
2988 Measure_menu:  !
2990                ! Original: 5 May 1984
2992                ! Revision: 24 Jan 1986
2994                !
2996                ! This routine will facilitate setting up the
2998                ! measurement by providing MENU access to the
3000                ! parameters.
3002                !
3004      COM /Parameters/ REAL Fstart,Fstop,Fstep
3006      COM /Parameters/ REAL Min_eut,Max_eut,Min_pwr,Max_pwr,Time_eut
3008      COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm
3010      COM /Parameters/ INTEGER Search_eut,Search_pwr,Re_run
3012      COM /Parameters/ INTEGER Begin_step,Total_steps,Total_meters
3014      COM /Parameters/ Run_id$,Measmt_id$,Time_date$
3016      COM /Parameters/ Meter_defns$(*),Operator_name$,Test_type$
3018      COM /Parameters/ Coupler_id$,Generator_id$
3020      !
3022      COM /Files/ Sourcedisk$,Outdisk$,Filename$
3024      COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
3026      COM /Interrupts/ INTEGER Intr_prty
3028      DIM Test$[160]
3030      INTEGER Local_prty,I,Ascii_num,Interrupted
3032      Local_prty=Intr_prty
3034      DISP CHR$(129)
3036      !
3038      IF Printer=701 THEN
3040          ON TIMEOUT 7,.5 GOSUB Printerdead
3042          PRINT
3044          OFF TIMEOUT
3046      END IF
3048      !
3050      IF Bug1 THEN
3052          PRINT TIME$(TIMEDATE);RPT$("*",10);" ENTER Measure_menu"
3054      END IF
3056      CALL Wipe_clean              ! Clear the CRT.
3058      PRINTER IS CRT
3060      GOSUB Write_backgnd          ! Format menu area.
3062      IF NOT Re_run THEN
3064          GOSUB Start_up_values    ! Initial values
3066                                   ! Put initial values in menu
3068      ELSE
3070          GOSUB Fill_in_values     ! Put current values in menu
3072      END IF
3074      !
3076      !Make any changes or corrections.
3078      !
3080      GOSUB Define_keys
3082      PRINT TABXY(56,3);DATE$(TIMEDATE)
3084      LOOP
3086          IF Interrupted THEN GOSUB Define_keys
3088          ON KEY 5 LABEL "EXIT    ^RESET",Local_prty GOTO Exit_sub
3090          ON KEY 15,Local_prty GOSUB Start_up_values
3092          PRINT TABXY(69,3);TIME$(TIMEDATE)
3094      END LOOP
3096 Exit_sub:!
```

```
2978   END
2980   !
2982   ! ************************************************************
2984   !
2986   SUB Measure_menu
2988 Measure_menu:  !
2990                ! Original: 5 May 1984
2992                ! Revision: 24 Jan 1986
2994                !
2996                ! This routine will facilitate setting up the
2998                ! measurement by providing MENU access to the
3000                ! parameters.
3002                !
3004       COM /Parameters/ REAL Fstart,Fstop,Fstep
3006       COM /Parameters/ REAL Min_eut,Max_eut,Min_pwr,Max_pwr,Time_eut
3008       COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm
3010       COM /Parameters/ INTEGER Search_eut,Search_pwr,Re_run
3012       COM /Parameters/ INTEGER Begin_step,Total_steps,Total_meters
3014       COM /Parameters/ Run_id$,Measmt_id$,Time_date$
3016       COM /Parameters/ Meter_defns$(*),Operator_name$,Test_type$
3018       COM /Parameters/ Coupler_id$,Generator_id$
3020       !
3022       COM /Files/ Sourcedisk$,Outdisk$,Filename$
3024       COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
3026       COM /Interrupts/ INTEGER Intr_prty
3028       DIM Test$[160]
3030       INTEGER Local_prty,I,Ascii_num,Interrupted
3032       Local_prty=Intr_prty
3034       DISP CHR$(129)
3036       !
3038       IF Printer=701 THEN
3040           ON TIMEOUT 7,.5 GOSUB Printerdead
3042           PRINT
3044           OFF TIMEOUT
3046       END IF
3048       !
3050       IF Bug1 THEN
3052           PRINT TIME$(TIMEDATE);RPT$("*",10);" ENTER Measure_menu"
3054       END IF
3056       CALL Wipe_clean              ! Clear the CRT.
3058       PRINTER IS CRT
3060       GOSUB Write_backgnd          ! Format menu area.
3062       IF NOT Re_run THEN
3064           GOSUB Start_up_values    ! Initial values
3066                                    ! Put initial values in menu
3068       ELSE
3070           GOSUB Fill_in_values     ! Put current values in menu
3072       END IF
3074       !
3076       !Make any changes or corrections.
3078       !
3080       GOSUB Define_keys
3082       PRINT TABXY(56,3);DATE$(TIMEDATE)
3084       LOOP
3086           IF Interrupted THEN GOSUB Define_keys
3088           ON KEY 5 LABEL "EXIT    ^RESET",Local_prty GOTO Exit_sub
3090           ON KEY 15,Local_prty GOSUB Start_up_values
3092           PRINT TABXY(69,3);TIME$(TIMEDATE)
3094       END LOOP
3096 Exit_sub:!
```

```
3098       OFF KEY
3100       DISP CHR$(12)
3102       Time_date$=TIME$(TIMEDATE)&", "&DATE$(TIMEDATE)
3104       PRINTER IS Printer
3106       IF Printer=701 THEN DUMP ALPHA
3108       IF Bug1 THEN
3110           PRINT TIME$(TIMEDATE);RPT$("*",10);" EXIT Measure_menu"
3112       END IF
3114       CALL Wipe_clean
3116       PRINTER IS CRT
3118       SUBEXIT
3120       !
3122       ! ////////////////////////////////////////////////////////////////////
3124       !
3126 Define_keys:!
3128       OFF KEY
3130       Interrupted=0
3132       DISP RPT$("<",15);"     SELECT PARAMETER TO CHANGE ";
3134       DISP " (^shift key)     ";RPT$(">",15)
3136       ON KEY 0 LABEL "TEST ID  ^TYPE",Local_prty GOSUB Change_eutid
3138       ON KEY 10,Local_prty GOSUB Change_type
3140       ON KEY 1 LABEL "FREQs ^SIG GEN",Local_prty GOSUB Change_freqs
3142       ON KEY 11,Local_prty GOSUB Change_levels
3144       ON KEY 2 LABEL "INPUT MIN ^MAX",Local_prty GOSUB Change_pwr_min
3146       ON KEY 12,Local_prty GOSUB Change_pwr_max
3148       ON KEY 3 LABEL "LEVEL  ^SEARCH",Local_prty GOSUB Change_search_p
3150       ON KEY 13,Local_prty GOSUB Change_search_e
3152       ON KEY 4 LABEL "EUT MIN   ^MAX",Local_prty GOSUB Change_eut_min
3154       ON KEY 14,Local_prty GOSUB Change_eut_max
3156       ON KEY 6 LABEL "DATE     ^NAME",Local_prty GOSUB Call_time_date
3158       ON KEY 16,Local_prty GOSUB Enter_name
3160       ON KEY 7 LABEL "Response Time",Local_prty GOSUB Change_response
3162       IF Test_type$<>"OTHER (NO STEPS)" THEN
3164           ON KEY 8 LABEL "TUNER   ^BEGIN",Local_prty GOSUB Change_tuner
3166           ON KEY 18,Local_prty GOSUB Change_beginstp
3168       END IF
3170       ON KEY 9 LABEL "DISK DRIVE",Local_prty GOSUB Change_diskdriv
3172       RETURN
3174       !
3176       ! ////////////////////////////////////////////////////////////////////
3178       !
3180 Start_up_values: ! Define the initial values for all parameters.
3182       Re_run=1
3184       Fstart=100          ! Frequency range in MHz.
3186       Fstop=1000
3188       Fstep=50
3190       Low_dbm=-40         ! Signal generator level in dBm.
3192       High_dbm=-10
3194       Step_dbm=1
3196       Search_eut=0        ! 0= DO NOT auto search for EUT response
3198                           ! 1= DO
3200       Search_pwr=0        ! 0= DO NOT auto level the Net Input power.
3202                           ! 1= DO
3204       Min_eut=1.0E-6      ! Minimum output of EUT in volts.
3206       Max_eut=10.0        ! Maximum output of EUT in volts.
3208       Min_pwr=1.0E-6      ! Minimum net input power in watts.
3210       Max_pwr=10.0        ! Maximum net input power in watts.
3212       Time_eut=0.         ! Time for EUT to respond after field is set.
3214       Begin_step=1
3216       Total_steps=200     !An integer division of 3200
```

```
3218        Test_type$="MODE TUNE REGULAR"   !or "MODE TUNE EMISSIONS"
3220                                         !or "OTHER (NO STEPS)"
3222        Run_id$="Run_1"
3224        Operator_name$="Galen Koepke"
3226        Measmt_id$="Evaluate the susceptability of a device"
3228        Measmt_id$=Measmt_id$&" in the NBS Reverberating Chamber."
3230        Coupler_id$="HP_778D"
3232        Generator_id$="HP_8660A"
3234        !
3236        GOSUB Fill_in_values  ! Put initial values in menu
3238        RETURN
3240        !
3242        ! ///////////////////////////////////////////////////////////////
3244        !
3246 Fill_in_values:!
3248        !
3250        GOSUB Change_eutid    ! Fill in the values
3252        GOSUB Print_type
3254        GOSUB Print_freqs
3256        GOSUB Print_gen_level
3258        GOSUB Print_beginstp
3260        GOSUB Print_tuner
3262        GOSUB Print_name
3264        GOSUB Print_search_p
3266        GOSUB Print_search_e
3268        GOSUB Print_eut_min
3270        GOSUB Print_eut_max
3272        GOSUB Print_pwr_min
3274        GOSUB Print_pwr_max
3276        GOSUB Print_wait
3278        GOSUB Print_diskdrive
3280        RETURN
3282        !
3284        ! ///////////////////////////////////////////////////////////////
3286        !
3288 Write_backgnd: ! Format menu area.
3290        PRINT CHR$(129)
3292        PRINT TABXY(16,1);" ***MEASUREMENT PARAMETERS -                       *** "
3294        PRINT TABXY(1,3);" TEST ID: "
3296        PRINT TABXY(23,3);" TYPE: "
3298        PRINT TABXY(41,3);" DATE / TIME: "
3300        !
3302        PRINT CHR$(132);
3304        PRINT TABXY(1,5);RPT$(" ",160)
3306        PRINT CHR$(129);
3308        !
3310        PRINT TABXY(1,8);" FREQUENCY (MHz) "
3312        PRINT TABXY(1,9);"  LOW: "
3314        PRINT TABXY(1,10);" HIGH: "
3316        PRINT TABXY(1,11);" STEP: "
3318        PRINT TABXY(21,8);" GENERATOR (dBm) "
3320        !
3322        PRINT TABXY(41,8);" NET INPUT POWER (W) "
3324        PRINT TABXY(41,9);"   MIN: "
3326        PRINT TABXY(41,10);"   MAX: "
3328        PRINT TABXY(41,11);" LEVEL INPUT? "
3330        PRINT TABXY(65,8);" EUT RESPONSE   "
3332        PRINT TABXY(65,11);" SEARCH? "
3334        PRINT CHR$(128);
3336        PRINT TABXY(62,9);"..."
```

```
3338        PRINT TABXY(62,10);"..."
3340        PRINT CHR$(129);
3342        PRINT TABXY(1,13);" ESTIMATE EUT RESPONSE TIME "
3344        PRINT TABXY(41,13);" seconds. ";RPT$(" ",30)
3346        PRINT TABXY(41,15);" COUPLER/SIG GEN:";
3348        PRINT TABXY(1,15);" BEGIN TUNER POSITION "
3350        PRINT TABXY(29,15);" END "
3352        PRINT TABXY(1,17);" OPERATOR: ";
3354        PRINT TABXY(41,17);" OUTPUT DISK DRIVE: "
3356        PRINT CHR$(128)
3358        RETURN
3360        !
3362        ! ///////////////////////////////////////////////////////////////////
3364        !
3366 Printerdead:DISP "NO PRINTER at HPIB address 701 !!";
3368        DISP "  Please correct situation and hit 'CONTINUE'"
3370        BEEP
3372        PAUSE
3374        RETURN
3376        !
3378        ! ///////////////////////////////////////////////////////////////////
3380        !
3382 Call_time_date:Interrupted=1
3384        CALL Time_date
3386        RETURN
3388        !
3390        ! ///////////////////////////////////////////////////////////////////
3392        !
3394 Change_eut_max:Interrupted=1
3396        IF Test_type$="MODE TUNE EMISSIONS" THEN RETURN
3398        DISP " ENTER the UPPER LIMIT for the EUT RESPONSE (your units) ";
3400        INPUT Max_eut
3402        IF Max_eut<Min_eut THEN
3404            Min_eut=Max_eut
3406            GOSUB Print_eut_min
3408        END IF
3410 Print_eut_max:!
3412        PRINT TABXY(66,10);
3414        IF Test_type$="MODE TUNE EMISSIONS" THEN
3416            PRINT USING "9A";" Not used"
3418        ELSE
3420            PRINT USING "MD.2DE";Max_eut
3422        END IF
3424        RETURN
3426        !
3428        ! ///////////////////////////////////////////////////////////////////
3430        !
3432 Change_eut_min:Interrupted=1
3434        IF NOT Search_eut OR Test_type$="MODE TUNE EMISSIONS" THEN RETURN
3436        DISP " ENTER the LOWER LIMIT for the EUT RESPONSE (your units) ";
3438        INPUT Min_eut
3440        IF Min_eut>Max_eut THEN Min_eut=Max_eut
3442 Print_eut_min:!
3444        PRINT TABXY(66,9);
3446        IF NOT Search_eut OR Test_type$="MODE TUNE EMISSIONS" THEN
3448            PRINT USING "9A";" Not used"
3450        ELSE
3452            PRINT USING "MD.2DE";Min_eut
3454        END IF
3456        RETURN
```

```
3458        !
3460        ! ///////////////////////////////////////////////////////////////
3462        !
3464 Change_pwr_max:Interrupted=1
3466        IF NOT Search_pwr OR Test_type$="MODE TUNE EMISSIONS" THEN RETURN
3468        DISP " ENTER the Maximum NET Input Power ";
3470        INPUT Max_pwr
3472        IF Max_pwr<0. THEN Max_pwr=0.
3474        IF Max_pwr<Min_pwr THEN
3476            Min_pwr=Max_pwr
3478            GOSUB Print_pwr_min
3480        END IF
3482 Print_pwr_max:!
3484        PRINT TABXY(50,10);
3486        IF NOT Search_pwr OR Test_type$="MODE TUNE EMISSIONS" THEN
3488            PRINT USING "9A";" Not used"
3490        ELSE
3492            PRINT USING "MD.2DE";Max_pwr
3494        END IF
3496        RETURN
3498        !
3500        ! ///////////////////////////////////////////////////////////////
3502        !
3504 Change_pwr_min:Interrupted=1
3506        IF Test_type$="MODE TUNE EMISSIONS" THEN RETURN
3508        DISP " ENTER the Minimum NET Input Power ";
3510        INPUT Min_pwr
3512        IF Min_pwr<0. THEN Min_pwr=0.
3514        IF Min_pwr>Max_pwr THEN Min_pwr=Max_pwr
3516 Print_pwr_min:!
3518        PRINT TABXY(50,9);
3520        IF Test_type$="MODE TUNE EMISSIONS" THEN
3522            PRINT USING "9A";" Not used"
3524        ELSE
3526            PRINT USING "MD.2DE";Min_pwr
3528        END IF
3530        RETURN
3532        !
3534        ! ///////////////////////////////////////////////////////////////
3536        !
3538 Change_search_p:!
3540        IF Search_pwr=0 AND Search_eut=0 THEN
3542            Search_pwr=1
3544        ELSE
3546            Search_pwr=0
3548        END IF
3550        GOSUB Print_gen_level
3552        GOSUB Print_pwr_max
3554 Print_search_p:!
3556        PRINT TABXY(56,11);
3558        IF Test_type$="MODE TUNE EMISSIONS" THEN
3560            PRINT "OFF"
3562        ELSE
3564            IF Search_pwr THEN
3566                PRINT "ON "
3568            ELSE
3570                PRINT "OFF"
3572            END IF
3574        END IF
3576        RETURN
```

```
3578        !
3580        ! ////////////////////////////////////////////////////////////////////
3582        !
3584 Change_search_e:!
3586        IF Search_eut=0 AND Search_pwr=0 THEN
3588            Search_eut=1
3590        ELSE
3592            Search_eut=0
3594        END IF
3596        GOSUB Print_gen_level
3598        GOSUB Print_eut_min
3600 Print_search_e:!
3602        PRINT TABXY(75,11);
3604        IF Test_type$="MODE TUNE EMISSIONS" THEN
3606            PRINT "OFF"
3608        ELSE
3610            IF Search_eut THEN
3612                PRINT "ON "
3614            ELSE
3616                PRINT "OFF"
3618            END IF
3620        END IF
3622        RETURN
3624        !
3626        ! ////////////////////////////////////////////////////////////////////
3628        !
3630 Change_type:!
3632        Interrupted=1
3634        OFF KEY
3636        DISP " SELECT MEASUREMENT TYPE. "
3638        ON KEY 0 LABEL "Source = ANT",Local_prty+1 GOTO Source_ant
3640        ON KEY 2 LABEL "Source = EUT",Local_prty+1 GOTO Source_eut
3642        ON KEY 4 LABEL "NO TUNER STP",Local_prty+1 GOTO Notunerstep
3644        LOOP
3646        END LOOP
3648 Source_ant:! Regular MODE TUNED TESTS with transmitting antenna
3650        Test_type$="MODE TUNE REGULAR"
3652        Measmt_id$="Evaluate the susceptability of a device"
3654        Measmt_id$=Measmt_id$&" in the NBS Reverberating Chamber."
3656        GOSUB Print_eutid
3658        GOTO New_type
3660 Source_eut:! Emissions using MODE TUNED sequence, EUT is source
3662        Test_type$="MODE TUNE EMISSIONS"
3664        Measmt_id$="Measure the radiated emissions of a device"
3666        Measmt_id$=Measmt_id$&" in the NBS Reverberating Chamber."
3668        GOSUB Print_eutid
3670        GOTO New_type
3672 Notunerstep:! Other measurements that require no TUNER stepping
3674        Test_type$="OTHER (NO STEPS)"
3676        Measmt_id$="Measure the response of a device to a field"
3678        Measmt_id$=Measmt_id$&" in the NBS 1.2 meter TEM CELL."
3680        GOSUB Print_eutid
3682 New_type:OFF KEY
3684        ! Update all the menu items affected by TYPE change.
3686        GOSUB Print_gen_level
3688        GOSUB Print_beginstp
3690        GOSUB Print_tuner
3692        GOSUB Print_search_e
3694        GOSUB Print_search_p
3696        GOSUB Print_gen_id
```

```
3698        GOSUB Print_pwr_min
3700        GOSUB Print_pwr_max
3702        GOSUB Print_eut_min
3704        GOSUB Print_eut_max
3706 Print_type:!
3708        PRINT CHR$(129);
3710        PRINT TABXY(45,1);
3712        SELECT Test_type$
3714        CASE "MODE TUNE REGULAR","MODE TUNE EMISSIONS"
3716            PRINT "MODE TUNED TESTS";
3718        CASE "OTHER (NO STEPS)"
3720            PRINT "TEM CELL TESTS  ";
3722        CASE ELSE
3724            PRINT "????????????????";
3726        END SELECT
3728        PRINT CHR$(128);
3730        PRINT TABXY(31,3);
3732        SELECT Test_type$
3734        CASE "MODE TUNE REGULAR"
3736            PRINT "REGULAR  "
3738        CASE "MODE TUNE EMISSIONS"
3740            PRINT "EMISSIONS"
3742        CASE "OTHER (NO STEPS)"
3744            PRINT "OTHER    "
3746        CASE ELSE
3748            PRINT "?????????"
3750        END SELECT
3752        RETURN
3754        !
3756        ! ////////////////////////////////////////////////////////////////
3758        !
3760 Change_beginstp:Interrupted=1
3762        IF Test_type$="OTHER (NO STEPS)" THEN GOTO Print_beginstp
3764        DISP " ENTER THE BEGINNING TUNER STEP NUMBER ";
3766        INPUT Begin_step
3768        IF Begin_step>Total_steps THEN Begin_step=Total_steps
3770 Print_beginstp:!
3772        PRINT TABXY(24,15);
3774        IF Test_type$<>"OTHER (NO STEPS)" THEN
3776            PRINT USING "4D";Begin_step
3778        ELSE
3780            PRINT USING "4A";"N/A "
3782        END IF
3784        RETURN
3786        !
3788        ! ////////////////////////////////////////////////////////////////
3790        !
3792 Change_tuner:!
3794        IF Test_type$="OTHER (NO STEPS)" THEN GOTO Print_tuner
3796        SELECT Total_steps
3798        CASE 3200
3800            Total_steps=100
3802        CASE 1600
3804            Total_steps=3200
3806        CASE 800
3808            Total_steps=1600
3810        CASE 400
3812            Total_steps=800
3814        CASE 200
3816            Total_steps=400
```

```
3818         CASE 100
3820             Total_steps=200
3822         CASE ELSE
3824             Total_steps=400
3826         END SELECT
3828 Print_tuner:!
3830         PRINT TABXY(35,15);
3832         IF Test_type$<>"OTHER (NO STEPS)" THEN
3834             PRINT USING "4D";Total_steps
3836         ELSE
3838             PRINT USING "4A";"N/A "
3840         END IF
3842         IF Begin_step>Total_steps THEN
3844             Begin_step=Total_steps
3846             GOSUB Print_beginstp
3848         END IF
3850         RETURN
3852         !
3854         ! //////////////////////////////////////////////////////////////////
3856         !
3858 Change_eutid:Interrupted=1
3860         DISP " ENTER the TEST ID# (LEGAL FILE NAME) ";
3862         OUTPUT 2 USING "K,#";Run_id$
3864         LINPUT Test$
3866         IF LEN(Test$)=0 THEN Change_eutid
3868         IF LEN(Test$)>10 THEN
3870             BEEP
3872             DISP " ERROR in NAME ENTRY--TOO MANY CHARACTERS, TRY AGAIN. "
3874             WAIT 1.8
3876             OUTPUT 2 USING "K,#";Filename$
3878             GOTO Change_eutid
3880         END IF
3882         FOR I=1 TO LEN(Test$)
3884             Ascii_num=NUM(Test$[I])
3886             SELECT Ascii_num
3888             CASE 65 TO 90,95,97 TO 122,48 TO 57
3890                 !Allowed characters
3892             CASE ELSE
3894                 BEEP
3896                 DISP "ERROR in NAME ENTRY--ILLEGAL CHARACTERS, TRY AGAIN."
3898                 WAIT 1.8
3900                 GOTO Change_eutid
3902             END SELECT
3904         NEXT I
3906         Run_id$=Test$
3908         !
3910         DISP " DESCRIPTION of the EUT and PURPOSE for test?? (<2 lines) ";
3912         OUTPUT 2 USING "K,#";Measmt_id$
3914         LINPUT Measmt_id$
3916 Print_eutid:!
3918         PRINT TABXY(12,3);RPT$(" ",10)
3920         PRINT TABXY(12,3);Run_id$
3922         PRINT CHR$(132);
3924         PRINT TABXY(1,5);RPT$(" ",160)
3926         PRINT TABXY(1,5);Measmt_id$
3928         PRINT CHR$(128);
3930         RETURN
3932         !
3934         ! //////////////////////////////////////////////////////////////////
3936         !
```

```
3938 Enter_freq_er: !
3940        DISP " ERROR in numeric entry or ILLEGAL value. "
3942        BEEP
3944        WAIT 1.8
3946 Change_freqs:Interrupted=1
3948        DISP " ENTER Start, Stop, Step frequencies (MHz). ";
3950        DISP "[Ranges: 1-30, 30-2000, 2000-18000]";
3952        LINPUT Test$
3954        ON ERROR GOTO Enter_freq_er
3956        Fstart=VAL(Test$)
3958        Fstop=VAL(Test$[POS(Test$,",")+1])
3960        Test$=Test$[POS(Test$,",")+1,LEN(Test$)]
3962        Fstep=VAL(Test$[POS(Test$,",")+1])
3964        OFF ERROR
3966        IF Fstop<Fstart THEN GOTO Enter_freq_er
3968        Fstart=MAX(MIN(Fstart,18000),1)
3970        Fstop=MAX(MIN(Fstop,18000),1)
3972        Fstep=MAX(MIN(Fstep,18000),.01)
3974        SELECT Fstart+(Fstop-Fstart)/2    !Mid point in the range of freq.
3976        CASE <=30      ! Set limits to 1-30 range
3978            IF Fstop>30 THEN Fstop=30
3980            Generator_id$="HP_8660A"
3982            Coupler_id$="CH_130_4"
3984        CASE <=2000    ! Set limits to 30-2000 range
3986            IF Fstart<30 THEN Fstart=30
3988            IF Fstop>2000 THEN Fstop=2000
3990            Coupler_id$="HP_778D"
3992            Generator_id$="HP_8660A"
3994        CASE >=2000    ! Set limits to 2000-18000 range
3996            IF Fstart<2000 THEN Fstart=2000
3998            Coupler_id$="HP_11692D"
4000            Generator_id$="HP_8672A"
4002        END SELECT
4004 Print_freqs:!
4006        PRINT TABXY(9,9);
4008        PRINT USING "5D.2D";Fstart
4010        PRINT TABXY(9,10);
4012        PRINT USING "5D.2D";Fstop
4014        PRINT TABXY(9,11);
4016        PRINT USING "5D.2D";Fstep
4018 Print_gen_id:!
4020        PRINT TABXY(59,15);RPT$(" ",21);
4022        IF Test_type$="MODE TUNE EMISSIONS" THEN
4024            PRINT TABXY(59,15);"Not used"
4026        ELSE
4028            PRINT TABXY(59,15);Coupler_id$;"/";Generator_id$
4030        END IF
4032        RETURN
4034        !
4036        ! ////////////////////////////////////////////////////////////
4038        !
4040 Change_levels:Interrupted=1
4042        IF Test_type$="MODE TUNE EMISSIONS" THEN RETURN
4044        IF Search_eut OR Search_pwr THEN
4046            DISP " ENTER the LOW, HIGH, STEP Signal generator LEVEL (dBm) ";
4048            DISP " ...integers only! ";
4050            INPUT Low_dbm,High_dbm,Step_dbm
4052            IF Low_dbm>High_dbm THEN Low_dbm=High_dbm   ! capped by high_dbm
4054            IF Step_dbm<1 THEN Step_dbm=1
4056        ELSE
```

```
4058            DISP " ENTER Signal generator LEVEL (dBm) ";
4060            DISP " ...integers only! ";
4062            INPUT Low_dbm
4064            IF High_dbm<Low_dbm THEN High_dbm=Low_dbm   ! capped by low_dbm
4066        END IF
4068 Print_gen_level:!
4070        PRINT CHR$(129);
4072        SELECT Test_type$
4074        CASE "MODE TUNE REGULAR","OTHER (NO STEPS)"
4076            IF Search_eut OR Search_pwr THEN
4078                PRINT TABXY(21,9);"   LOW: "
4080                PRINT TABXY(21,10);"  HIGH: "
4082                PRINT TABXY(21,11);"  STEP: "
4084            ELSE
4086                PRINT TABXY(21,9);" FIXED: "
4088                PRINT TABXY(21,10);"        "
4090                PRINT TABXY(21,11);"        "
4092            END IF
4094        CASE "MODE TUNE EMISSIONS"
4096            PRINT TABXY(21,9);"   NOT  "
4098            PRINT TABXY(21,10);"   USED "
4100            PRINT TABXY(21,11);"   .... "
4102        CASE ELSE
4104            PRINT TABXY(21,9);"  ERROR "
4106            PRINT TABXY(21,10);"DETECTED"
4108            PRINT TABXY(21,11);"IN TYPE!"
4110        END SELECT
4112        PRINT CHR$(128);
4114        PRINT TABXY(30,9);
4116        PRINT USING "4A";"    "
4118        PRINT TABXY(30,10);
4120        PRINT USING "4A";"    "
4122        PRINT TABXY(30,11);
4124        PRINT USING "4A";"    "
4126        IF Test_type$<>"MODE TUNE EMISSIONS" THEN
4128            PRINT TABXY(30,9);
4130            PRINT USING "4D";Low_dbm
4132            IF Search_eut OR Search_pwr THEN
4134                PRINT TABXY(30,10);
4136                PRINT USING "4D";High_dbm
4138                PRINT TABXY(30,11);
4140                PRINT USING "4D";Step_dbm
4142            END IF
4144        END IF
4146        RETURN
4148        !
4150        ! ////////////////////////////////////////////////////////////////////
4152        !
4154 Change_response:Interrupted=1
4156        DISP " ENTER time for EUT to respond after field is set. (seconds) ";
4158        INPUT Time_eut
4160 Print_wait:!
4162        PRINT TABXY(30,13);
4164        IF Time_eut<9999 THEN
4166            PRINT USING "X,5D.3D";Time_eut
4168        ELSE
4170            PRINT USING "MD.3DE";Time_eut
4172        END IF
4174        RETURN
4176        !
```

```
4178        ! ////////////////////////////////////////////////////////////////
4180        !
4182 Enter_name:Interrupted=1
4184        DISP " PLEASE TYPE IN YOUR NAME ";
4186        LINPUT Test$
4188        Operator_name$=Test$[1,28]
4190 Print_name:!
4192        PRINT TABXY(13,17);RPT$(" ",28);
4194        PRINT TABXY(13,17);Operator_name$
4196        RETURN
4198        !
4200        ! ////////////////////////////////////////////////////////////////
4202        !
4204 Change_diskdriv:!
4206        OFF KEY
4208        Interrupted=1
4210        DISP " SELECT DISK DRIVE for DATA OUTPUT. "
4212        ON KEY 0 LABEL "LEFT Internal",Local_prty+1 GOTO Left_internal
4214        ON KEY 2 LABEL "9133 HARD DISK",Local_prty+1 GOTO Hard9133
4216        ON KEY 4 LABEL "RIGHT Internal",Local_prty+1 GOTO Right_internal
4218        ON KEY 7 LABEL "9133 floppy",Local_prty+1 GOTO Floppy9133
4220        LOOP
4222        END LOOP
4224 Left_internal:Outdisk$=":INTERNAL,4,1"
4226        GOTO Disk_selected
4228 Right_internal:Outdisk$=":INTERNAL,4,0"
4230        GOTO Disk_selected
4232 Hard9133:Outdisk$=":HP9133,700,0"
4234        GOTO Disk_selected
4236 Floppy9133:Outdisk$=":HP9133,702,0"
4238 Disk_selected:OFF KEY
4240 Print_diskdrive:!
4242        PRINT TABXY(62,17);Outdisk$
4244        RETURN
4246        !
4248        ! ////////////////////////////////////////////////////////////////
4250        !
4252   SUBEND
4254   !
4256   ! ************************************************************
4258   !
```

```
100!   RE-STORE "MODE_STIR"
102    ! Original: 22 May 1984, G. Koepke, NBS (303) 497-5766
104    ! Revision: 02 Oct 1985
106    ! ..........................................................
108    ! The program is currently configured as follows:
110    !      1) Read diode detector on DVM 1 [722] (Horn antenna)
112    !         Calibrate this reading via diode calibration
114    !         and normalize to 10 mW/cm^2 referenced to the
116    !         energy calculated via reference antenna as read
118    !         on the spectrum analyzer.
120    !
122    !      2) Read 1cm dipole output on DVM 2 [723] and DVM 3 [724]
124    !         This is the EUT for the measurement.
126    !         Calibrate via calibration curve and
128    !         normalize to 37 dB V/m as calculated from
130    !         reference received power.
132    !
134    !      3) In the event of failure to complete revolution
136    !         the program will modify sample count to compensate.
138    !
140    !      4) Parameters set for NBS chamber.
142    !
144    !      5) Save data is disabled, needs to be updated for GRAPH_DATA
146    !
148    ! ..........................................................
150    !
152    ! ==== CHECK ALL CABLES AND PAD PLACEMENTS ============
154    !
156    !This measurement routine will operate the REVERBERATION CHAMBER
158    !using MODE STIRED techniques.  The tuner is stepped continuously
160    !and measurements are performed asyncronusly. In this version each
162    !frequency is measured completely before proceeding
164    !to the next frequency.
166    !Coupler, cable loss, and Power meter head corrections are applied
168    !immediately to the measured data.
170    !The statistical results are saved for graphing.
172    !
174    !
176     OPTION BASE 1
178     DEG
180     PRINTER IS 1
182     OUTPUT 2 USING "K,#";"SCRATCH KEYX"
184     DISP CHR$(129)
186     !
188     GOSUB Die_gracefully      !For a clean slate.
190     GOSUB Dim_variables
192     GOSUB Initial_values
194     GOSUB Fillcalibration
196     GOSUB Do_measurements
198     GOSUB Die_gracefully
200     DISP "PROGRAM FINISHED"
202     STOP
204    !
206    !//////////////////////****DIMENSION VARIABLES****///////////////
208    !
210 Dim_variables:  !
212     COM /Parameters/ Startf,Stopf,Stepf,Slow_down,Coupler_id$[10]
214     COM /Parameters/ Generator_id$[10],Dvm_integrat$[3]
216     COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm,Dvm_samples
218     COM /Parameters/ Upperlimit,Threshold,Rev_time
```

```
220     COM /Motor_menu/ Motion_type$[10],INTEGER Jog_wait
222     COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
224     COM /Interrupts/ INTEGER Intr_prty
226     COM /Files/ Sourcedisk$[20],Outdisk$[20],Filename$[80]
228     !
230     DIM Coup_inc(100,2),Coup_refl(100,2),Baddata_id$(10)[80]
232     DIM Cable6a(180,2),Cable6b(180,2),Cable4(180,2),Cable10ft(180,2)
234     DIM Pad_as6a(180,2),Pad_s6770(180,2),Pad_f5530(180,2)
236     DIM Nswc(180,2)   !NSWC CABLE DATA
238     !
240     DIM Cal_id$[80],Ab$[2],Pwr_id$[2],Test$[40]
242     !
244     INTEGER Baddata,Dbm,Rf_on_off
246     INTEGER Failflag
248     INTEGER Valid,Totalfreqs,Totalcurves,Ser_poll
250     INTEGER Printflag,Read1flag,Read2flag,Movingflag,Pad10db
252     !
254     INTEGER Nswc_pts
256     INTEGER Inc_pts,Refl_pts,C6a_pts
258     INTEGER C6b_pts,C4_pts,C10_pts,Pada_pts,Pad_pts,Padf_pts
260     INTEGER Fcount,Too_hot,Printflag2
262     INTEGER Local_prty,P_sams,P,Dvm1_sams,Dvm2_sams
264     !
266     RETURN
268    !
270    !////////////////****INITIALIZE VARIABLES & I/O****/////////////
272    !
274 Initial_values:  !
276    !
278     ASSIGN @Motor TO 706
280     ASSIGN @Pwr1 TO 709
282     ASSIGN @Pwr2 TO 710
284     ASSIGN @Dual_pwr1 TO 711
286     ASSIGN @Spectrum TO 718
288     ASSIGN @Dvm1 TO 722
290     ASSIGN @Dvm2 TO 723
292     ASSIGN @Dvm3 TO 724
294     ASSIGN @Sig_gen TO 719
296     !
298     Intr_prty=6
300     Local_prty=Intr_prty
302     Printer=701
304     Sourcedisk$=":INTERNAL,4,0"
306     Outdisk$=":INTERNAL,4,1"
308     !
310     Printflag=0
312     Bug1=0
314     Bug2=0
316     Bug3=0
318     !
320     Motion_type$="CONTINUOUS"      !or "STEP" for MODE TUNED.
322     !
324     Rf_on_off=1                    ! 1=on,  0=off
326     !
328     CALL Measure_menu             !Go and set up the measurement parameters.
330     Dvm1_sams=Dvm_samples
332     Dvm2_sams=Dvm_samples
334     CALL Menu_pwr436a             !Set up all power meters
336     GOSUB Die_gracefully          !For a clean slate.
338     !
```

```
340     !-----------------ALLOCATE THE RAW DATA MATRIX------------------
342     Totalfreqs=INT((Stopf-Startf)/Stepf)+1
344     Totalcurves=6
346     ALLOCATE Savedata(Totalfreqs,Totalcurves+1)
348     ALLOCATE Adjust(Totalfreqs,10)
350     !---------------------------------------------------------------
352     !
354     PRINTER IS CRT
356     PRINT TABXY(1,18);RPT$("*",20);" LOAD SUB PROGRAMS ";RPT$("*",20)
358     Filename$=Generator_id$&Sourcedisk$
360     DISP "Insert 'SUB Program/Support DATA' disk in ";
362     SELECT Sourcedisk$
364     CASE ":INTERNAL,4,0"
366         DISP "RIGHT DRIVE, ";
368     CASE ":INTERNAL,4,1"
370         DISP "LEFT DRIVE, ";
372     END SELECT
374     DISP "and hit 'CONTINUE'."
376     BEEP
378     ON KEY 5 LABEL "CONTINUE",Local_prty GOTO Subloads
380 Zippy:GOTO Zippy
382 Subloads:OFF KEY
384     DISP CHR$(12)
386     DISP " Signal Generator SUB PROGRAMS NOW LOADING "
388     ON ERROR CALL Errortrap
390     LOADSUB ALL FROM Filename$
392     OFF ERROR
394     DISP " Signal Generator SUB PROGRAMS LOADED "
396     WAIT 1
398     !
400     PRINT TABXY(1,18);RPT$("*",20);" LOAD CALIBRATION DATA ";RPT$("*",20)
402     DISP " Calibration DATA for Cables, Couplers, Pads, etc. now LOADING "
404     !
406 Install_cal_fl:!.... Install new calibration files here....!
408     !
410     IF Printflag THEN PRINTER IS Printer
412     IF Printflag THEN PRINT "CALIBRATION DATA FOR THE FOLLOWING IS LOADED:"
414     SELECT Coupler_id$
416     CASE "HP_778D"
418         Filename$="HP_778D_f"&Sourcedisk$
420         Enter_caldata(Filename$,Coup_inc(*),Cal_id$,Inc_pts)
422         Baddata_id$(1)=Cal_id$
424         IF Printflag THEN PRINT Cal_id$
426         Filename$="HP_778D_r"&Sourcedisk$
428         Enter_caldata(Filename$,Coup_refl(*),Cal_id$,Refl_pts)
430         Baddata_id$(2)=Cal_id$
432         IF Printflag THEN PRINT Cal_id$
434     CASE "HP_11692D"
436         Filename$="HP11692D_f"&Sourcedisk$
438         Enter_caldata(Filename$,Coup_inc(*),Cal_id$,Inc_pts)
440         Baddata_id$(1)=Cal_id$
442         IF Printflag THEN PRINT Cal_id$
444         Filename$="HP11692D_r"&Sourcedisk$
446         Enter_caldata(Filename$,Coup_refl(*),Cal_id$,Refl_pts)
448         Baddata_id$(2)=Cal_id$
450         IF Printflag THEN PRINT Cal_id$
452     CASE ELSE
454         PRINT "COUPLER CALIBRATION DATA ERROR.....NOT DEFINED."
456         BEEP
458         PAUSE
```

```
460    END SELECT
462    !
464    !--------------------------------------------------------------------------
466    !
468    Filename$="Cable6FT_1"&Sourcedisk$
470    Enter_caldata(Filename$,Cable6a(*),Cal_id$,C6a_pts)
472    Baddata_id$(3)=Cal_id$
474    IF Printflag THEN PRINT Cal_id$
476    !
478    Filename$="Cable6FT_6"&Sourcedisk$
480    Enter_caldata(Filename$,Cable6b(*),Cal_id$,C6b_pts)
482    Baddata_id$(4)=Cal_id$
484    IF Printflag THEN PRINT Cal_id$
486    !
488    Filename$="Cable4FT_2"&Sourcedisk$
490    Enter_caldata(Filename$,Cable4(*),Cal_id$,C4_pts)
492    Baddata_id$(5)=Cal_id$
494    IF Printflag THEN PRINT Cal_id$
496    !
498    Filename$="Cable10F_5"&Sourcedisk$
500    Enter_caldata(Filename$,Cable10ft(*),Cal_id$,C10_pts)
502    Baddata_id$(6)=Cal_id$
504    IF Printflag THEN PRINT Cal_id$
506    !
508    Filename$="PAD_S6770"&Sourcedisk$
510    Enter_caldata(Filename$,Pad_s6770(*),Cal_id$,Pad_pts)
512    Baddata_id$(7)=Cal_id$
514    IF Printflag THEN PRINT Cal_id$
516    !
518    Filename$="PAD_5530"&Sourcedisk$
520    Enter_caldata(Filename$,Pad_f5530(*),Cal_id$,Padf_pts)
522    Baddata_id$(8)=Cal_id$
524    IF Printflag THEN PRINT Cal_id$
526    !
528    Filename$="PdAS6A1466"&Sourcedisk$
530    Enter_caldata(Filename$,Pad_as6a(*),Cal_id$,Pada_pts)
532    Baddata_id$(9)=Cal_id$
534    IF Printflag THEN PRINT Cal_id$
536    !
538    Filename$="PdAS6A1466"
540    Filename$=Filename$&Sourcedisk$
542    Enter_caldata(Filename$,Nswc(*),Cal_id$,Nswc_pts)
544    Baddata_id$(10)=Cal_id$
546    IF Printflag THEN PRINT Cal_id$
548    DISP " Calibration DATA LOADED "
550    WAIT 1
552    PRINTER IS CRT
554    CALL Wipe_clean
556    !
558    !----------------------------------------------------------------------------
560    !
562    DISP "INSERT OUTPUT DATA DISK IN ";
564    SELECT Outdisk$
566    CASE ":INTERNAL,4,0"
568        DISP "RIGHT DRIVE, ";
570    CASE ":INTERNAL,4,1"
572        DISP "LEFT DRIVE, ";
574    END SELECT
576    DISP "and hit 'CONTINUE'."
578    BEEP
```

```
580    ON KEY 5 LABEL "CONTINUE",Local_prty GOTO Datasaver
582 Zippity:GOTO Zippity
584 Datasaver:OFF KEY
586    DISP CHR$(12)
588    !
590    RETURN
592    !
594    !//////////////////////////////****DIE GRACEFULLY****////////////////
596    !
598 Die_gracefully:   !
600    IF Bug1 THEN
602        PRINT TIME$(TIMEDATE);
604        PRINT RPT$("<",15);" DIE GRACEFULLY ";RPT$(">",15)
606    END IF
608    ON ERROR GOTO Delet_done1
610    SELECT Generator_id$
612    CASE "HP_8660A"
614        DELSUB Set_freq,Set_dbm,FNDigit10$,FNDigit3$,FNRev$
616    CASE "HP_8672A"
618        DELSUB Set_freq,Set_dbm
620    END SELECT
622 Delet_done1:   !
624    OFF ERROR
626    ON ERROR GOTO Delet_done2
628    DEALLOCATE Savedata(*),Adjust(*)
630 Delet_done2:   !
632    OFF ERROR
634    RETURN
636    !
638    ! //////////////////////////////////////////////////////////////////
640    !
642 Fillcalibration:     !Determine the cable, coupler and pad calibration
644                      !values for each frequency.
646                      !Save these in the adjust(*) file for use by the
648                      !measurement routine.
650                      !
652    IF Bug1 THEN
654        PRINT TIME$(TIMEDATE);
656        PRINT RPT$("<",15);" FILL CALIBRATION MATRIX ";RPT$(">",15)
658    END IF
660    Fcount=1
662    FOR Frequency=Startf TO Stopf STEP Stepf
664        Get_cal_value(Frequency,Coupinc,Coup_inc(*),Baddata,Inc_pts)
666        IF Baddata THEN
668            Cal_id$=Baddata_id$(1)
670            GOSUB Flagbaddata
672        END IF
674        Adjust(Fcount,1)=Coupinc
676            !
678        Get_cal_value(Frequency,Coupref1,Coup_ref1(*),Baddata,Ref1_pts)
680        IF Baddata THEN
682            Cal_id$=Baddata_id$(2)
684            GOSUB Flagbaddata
686        END IF
688        Adjust(Fcount,2)=Coupref1
690            !
692        Get_cal_value(Frequency,C6a_loss,Cable6a(*),Baddata,C6a_pts)
694        IF Baddata THEN
696            Cal_id$=Baddata_id$(3)
698            GOSUB Flagbaddata
```

```
700          END IF
702          Adjust(Fcount,3)=C6a_loss
704              !
706          Get_cal_value(Frequency,C6b_loss,Cable6b(*),Baddata,C6b_pts)
708          IF Baddata THEN
710              Cal_id$=Baddata_id$(4)
712              GOSUB Flagbaddata
714          END IF
716          Adjust(Fcount,4)=C6b_loss
718              !
720          Get_cal_value(Frequency,C4_loss,Cable4(*),Baddata,C4_pts)
722          IF Baddata THEN
724              Cal_id$=Baddata_id$(5)
726              GOSUB Flagbaddata
728          END IF
730          Adjust(Fcount,5)=C4_loss
732              !
734          Get_cal_value(Frequency,C10_loss,Cable10ft(*),Baddata,C10_pts)
736          IF Baddata THEN
738              Cal_id$=Baddata_id$(6)
740              GOSUB Flagbaddata
742          END IF
744          Adjust(Fcount,6)=C10_loss
746              !
748          Get_cal_value(Frequency,Pad_loss,Pad_s6770(*),Baddata,Pad_pts)
750          IF Baddata THEN
752              Cal_id$=Baddata_id$(7)
754              GOSUB Flagbaddata
756          END IF
758          Adjust(Fcount,7)=Pad_loss
760              !
762          Get_cal_value(Frequency,Padf_loss,Pad_f5530(*),Baddata,Padf_pts)
764          IF Baddata THEN
766              Cal_id$=Baddata_id$(8)
768              GOSUB Flagbaddata
770          END IF
772          Adjust(Fcount,8)=Padf_loss
774              !
776          Get_cal_value(Frequency,Pada_loss,Pad_as6a(*),Baddata,Pada_pts)
778          IF Baddata THEN
780              Cal_id$=Baddata_id$(9)
782              GOSUB Flagbaddata
784          END IF
786          Adjust(Fcount,9)=Pada_loss
788              !
790          Get_cal_value(Frequency,Nswc_loss,Nswc(*),Baddata,Nswc_pts)
792          IF Baddata THEN
794              Cal_id$=Baddata_id$(10)
796              GOSUB Flagbaddata
798          END IF
800          Adjust(Fcount,10)=Nswc_loss
802          !
804          Fcount=Fcount+1
806      NEXT Frequency
808      GOSUB Printcalvalues
810      RETURN
812      !
814      ! /////////////****FLAG BAD DATA****/////////////////////////
816      !
818 Flagbaddata:       !Inform the operator that there is wrong data
```

```
820                   !being brought back from Enter_cal_data
822                   !
824    PRINTER IS CRT
826    PRINT TABXY(1,18);
828    PRINT RPT$("*",10);" CALIBRATION DATA out of range for ";Frequency;
830    PRINT " MHz ";RPT$("*",10)
832    DISP Cal_id$
834    BEEP
836    PAUSE
838    PRINT TABXY(1,18);
840    PRINT RPT$("*",10);" CALIBRATION VALUE OF 0 dB WILL BE USED ";
842    PRINT RPT$("*",10)
844    WAIT 3
846    PRINT TABXY(1,18);RPT$(" ",80)
848    DISP CHR$(12)
850    RETURN
852    !
854    ! ////////////////////////////////////////////////////////////
856    !
858 Printcalvalues:      !MAKE LIST OF CALIBRATION VALUES USED.
860                      !
862    PRINTER IS Printer
864    PRINT
866    PRINT RPT$("*",24);" CALIBRATION / LOSS VALUES (dB) ";RPT$("*",24)
868    PRINT
870    PRINT "Frequency   Coupler     ----- BLUE CABLES -----";
872    PRINT " S6770  F5530  ASA6A TEST"
874    PRINT "   MHz     Inc    Refl    6ft#1 6ft#6    4ft   10ft";
876    PRINT "  pad    pad    pad    Cbl"
878 Lossfmt1:IMAGE M5D.D,X,4(MDD.DD),#
880 Lossfmt2:IMAGE 3(MDD.DD),2(MDD.DD,X),#
882 Lossfmt3:IMAGE MDD.DD
884    Fcount=1
886    FOR Frequency=Startf TO Stopf STEP Stepf
888        Coupinc=10*LGT(Adjust(Fcount,1))            !Coupler incident
890        Coupref1=10*LGT(Adjust(Fcount,2))           !Coupler reflected
892        C6a_loss=10*LGT(Adjust(Fcount,3))           !6 foot BLUE cable #1
894        C6b_loss=10*LGT(Adjust(Fcount,4))           !6 foot BLUE cable #6
896        C4_loss=10*LGT(Adjust(Fcount,5))            !4 foot BLUE cables
898        C10_loss=10*LGT(Adjust(Fcount,6))           !10 foot BLUE cables
900        Pad_loss=10*LGT(Adjust(Fcount,7))           !Weinschel S6770 10dB pad
902        Padf_loss=10*LGT(Adjust(Fcount,8))          !Weinschel F5530 10dB pad
904        Pada_loss=10*LGT(Adjust(Fcount,9))          !Weinschel AS6A-1466 10dB
906        Nswc_loss=10*LGT(Adjust(Fcount,10))         !NSWC input cable
908        PRINT USING Lossfmt1;Frequency,Coupinc,Coupref1,C6a_loss,C6b_loss
910        PRINT USING Lossfmt2;C4_loss,C10_loss,Pad_loss,Padf_loss,Pada_loss
912        PRINT USING Lossfmt3;Nswc_loss
914        Fcount=Fcount+1
916    NEXT Frequency
918    PRINT
920    PRINT RPT$("*",80)
922    PRINT USING "4/"
924    PRINTER IS CRT
926    RETURN
928    !
930    !
932    !//////////////////////****PERFORM MEASUREMENTS****///////////////
934    !
936 Do_measurements:    !
938    !
```

```
940     PRINTER IS 1
942     Fcount=1
944     Dbm=Low_dbm              !Initialize the Generator Level
946     Frequency=Startf         !Initialize first frequency.
948     ! BEEP
950     ! INPUT "ENTER THE RANGE SET ON THE 1 cm DIPOLE AMPLIFIER",P1cm_scale
952     ! DISP CHR$(12)
954     P1cm_scale=.1
956     Initializemotor(@Motor)
958     Zeromotor(@Motor)
960     !
962     REPEAT
964         !
966         !Initial values and zeroing
968         !
970         !Calibration data for all cables, probes, & power heads.
972         !
974         Pwrmtrcal1=FNPwrmtrcal1((Frequency))         !18 GHz HEAD.
976         Pwrmtrcal2=FNPwrmtrcal2((Frequency))         !26 GHz HEAD.
978         !
980         Coupinc=Adjust(Fcount,1)            !Coupler incident
982         Couprefl=Adjust(Fcount,2)           !Coupler reflected
984         C6a_loss=Adjust(Fcount,3)           !6 foot BLUE cable #1
986         C6b_loss=Adjust(Fcount,4)           !6 foot BLUE cable #6 rcvr.
988         C4_loss=Adjust(Fcount,5)            !4 foot BLUE cable
990         C10_loss=Adjust(Fcount,6)           !10 foot BLUE cable
992         Pad_loss=Adjust(Fcount,7)           !Weinschel S6770 10dB pad
994         Padf_loss=Adjust(Fcount,8)          !Weinschel F5530 10dB pad
996         Pada_loss=Adjust(Fcount,9)          !Weinschel AS6A-1466 10dB
998         Nswc_loss=Adjust(Fcount,10)         !NSWC input cable
1000        !
1002        Dvm1_sams=Dvm_samples     !The measurement will be attempted at
1004        Dvm2_sams=Dvm_samples     !the predicted number of samples first.
1006                                  !These will be adjusted if failure occurs.
1008        Failflag=0
1010        !
1012 Restart:  !Any failure on this measurement causes branch to here.
1014        Set_dbm(-140,Rf_on_off,@Sig_gen)
1016        Set_freq(Frequency,@Sig_gen)
1018        Initializemotor(@Motor)
1020        !
1022        DISP CHR$(12)
1024        !
1026        Setdcv3456a(@Dvm1)
1028        Readdvm(Eut_zero,@Dvm1)
1030        Setdcv3456a(@Dvm2)
1032        Readdvm(P1cm_zero,@Dvm2)
1034        !
1036        Setdvm_3456a(@Dvm1,Dvm_integrat$,Dvm1_sams)
1038        Setdvm_3456a(@Dvm2,Dvm_integrat$,Dvm2_sams)
1040        Setdvm_3478a(@Dvm3)
1042        Spec_alzr_setup(@Spectrum)
1044        !
1046        !Zero_pwr_mtrs(@Pwr1,@Pwr2)
1048        !
1050        Ab$="AB"
1052        CALL Zero_438a(@Dual_pwr1,Ab$)
1054        !
1056        IF NOT Failflag THEN
1058            Dbm=Low_dbm
```

```
1060           Movemotor(@Motor)
1062           PRINT CHR$(12)
1064           PRINT TABXY(1,3);TIME$(TIMEDATE);"***************";
1066           PRINT " FREQUENCY ";Frequency;" MHz.  ***************"
1068           PRINT TABXY(1,5);"FINDING THRESHOLD VALUE dBm="
1070           PRINT TABXY(36,5);" Average EUT RESPONSE= "
1072           LOOP
1074               Set_dbm(Dbm,Rf_on_off,@Sig_gen)
1076               Vave=0.
1078               FOR Sams=1 TO 30
1080                   Readdvm_3478a(@Dvm3,V)
1082                   V=V-P1cm_zero
1084                   Vave=Vave+V
1086               NEXT Sams
1088               Vave=Vave/40
1090               PRINT TABXY(30,5);
1092               PRINT USING "5D";Dbm
1094               PRINT TABXY(60,5);
1096               PRINT USING "3D.8D";Vave
1098           EXIT IF Vave>=Threshold OR Dbm>=High_dbm
1100               Dbm=Dbm+Step_dbm
1102           END LOOP
1104           Stop_motor(@Motor)
1106       ELSE
1108           Set_dbm(Dbm,Rf_on_off,@Sig_gen)
1110       END IF
1112       Failflag=1
1114       !
1116       ! Trigger measurement .............................
1118       !
1120       DISP CHR$(12)
1122 Restart_point2:!
1124       Ab$="AB"
1126       CALL Read_dual_pwr(Ab$,Apower,Bpower,Too_hot,Valid,@Dual_pwr1)
1128       IF Too_hot THEN
1130           GOSUB Reduce_power
1132           GOTO Restart_point2
1134       END IF
1136       IF NOT Valid AND NOT Too_hot THEN GOSUB Dual_pwr_error
1138       IF Apower<0. THEN Apower=0.
1140       IF Bpower<0. THEN Bpower=0.
1142       Incpwr_raw=Apower
1144       Refpwr_raw=Bpower
1146       !
1148       !....Sequence for reading 436a Power meters.................
1150       !     Pwr_id$="P1"
1152       !     Read_pwr_meter(Power,Pwr_id$,Valid,@Pwr1,@Sig_gen)
1154       !     IF NOT Valid THEN
1156       !         DISP "ERROR IN 436a POWER METER 1"
1158       !         BEEP
1160       !         PAUSE
1162       !     END IF
1164       !...........................................................
1166       Incpwr=Incpwr_raw
1168       Incpwr=Incpwr*Coupinc*Pwrmtrcal1/(C6b_loss)  !Inc power at ANT
1170       Refpwr=Refpwr_raw*Couprefl*Pwrmtrcal1*C6b_loss !Refl pwr at ANT
1172       Netpower=(Incpwr-Refpwr)
1174       !
1176       PRINT TIME$(TIMEDATE);
1178       PRINT "**** START NEW MEASURMENT AT FREQUENCY = ";Frequency
```

```
1180        ON INTR 7 GOSUB Check_dvm_done
1182        ENABLE INTR 7;2
1184        Movemotor(@Motor)
1186        IF Bug1 THEN PRINT "DVM1 trigger ";TIME$(TIMEDATE);" ";
1188        Trig1_time=TIMEDATE
1190        Trigger_3456a(@Dvm1)
1192        IF Bug1 THEN PRINT "DVM2 trigger ";TIME$(TIMEDATE);" ";
1194        Trig2_time=TIMEDATE
1196        Trigger_3456a(@Dvm2)
1198        Spec_alzr_start(Frequency,@Spectrum)
1200        IF Bug1 THEN PRINT "TRIGGER ANALYZER ";TIME$(TIMEDATE)
1202        Read1flag=0
1204        Read2flag=0
1206        Vpeak=0
1208        LOOP
1210            Readdvm_3478a(@Dvm3,V)
1212            V=V-P1cm_zero
1214            IF V>=Upperlimit THEN
1216                Stop_motor(@Motor)
1218                REPEAT
1220                    Dbm=Dbm-Step_dbm
1222                    Set_dbm(Dbm,Rf_on_off,@Sig_gen)
1224                    WAIT Slow_down
1226                    Readdvm_3478a(@Dvm3,V)
1228                    V=V-P1cm_zero
1230                    BEEP
1232                    PRINT "EUT MAXIMUM EXCEEDED **** POWER DECREASED TO ";
1234                    PRINT Dbm;" dBm."
1236                UNTIL V<Upperlimit
1238                OFF INTR 7
1240                GOTO Restart
1242            END IF
1244            Checkmotor(@Motor,Movingflag)
1246            IF NOT Movingflag THEN
1248                PRINT "MOTOR NOT MOVING********DATA BAD"
1250                GOTO Restart
1252            END IF
1254            IF V>Vpeak THEN Vpeak=V
1256            Countdown=Rev_time-(TIMEDATE-Trig1_time)
1258 Spy:       IMAGE  M4D.D," Seconds left, EUT mV=",M6D.2D," / ",M6D.2D,"  "
1260            DISP USING Spy;Countdown,V*1000,Vpeak*1000
1262        EXIT IF Read1flag AND Read2flag
1264        END LOOP
1266        !========================================
1268        ! Make sure that the correct voltmeters are connected for this test!
1270        ! IF (Vpeak+Eut_zero)>High2 THEN High2=Vpeak+Eut_zero
1272        !========================================
1274        OFF INTR 7
1276        Failflag=0
1278        !
1280        ! Insure successful (syncronized tuner and dvms)  measurement.
1282        !
1284        IF (Read1_time<.98*Rev_time) OR (Read1_time>1.02*Rev_time) THEN
1286            Dvm1_sams=INT((Rev_time/Read1_time)*Dvm1_sams)
1288            PRINT "Dvm 1 NOT syncronized with TUNER REVOLUTION. ";
1290            PRINT "Changing samples to ";Dvm1_sams
1292            Failflag=1
1294        END IF
1296        IF (Read2_time<.98*Rev_time) OR (Read2_time>1.02*Rev_time) THEN
1298            Dvm2_sams=INT((Rev_time/Read2_time)*Dvm2_sams)
```

```
1300            PRINT "Dvm 2 NOT syncronized with TUNER REVOLUTION. ";
1302            PRINT "Changing samples to ";Dvm2_sams
1304            Failflag=1
1306        END IF
1308        IF Failflag THEN
1310            Stop_motor(@Motor)
1312            GOTO Restart
1314        END IF
1316        Spec_alzr_read(Power,Frequency,@Spectrum)
1318        PRINT "SPECTRUM ANALYZER READS ";Power;" AT FREQUENCY ";Frequency
1320        Stop_motor(@Motor)
1322        Set_dbm(-140,Rf_on_off,@Sig_gen)
1324        !
1326        GOSUB Process_data
1328        GOSUB Print_alldata
1330        !
1332        Frequency=Frequency+Stepf
1334        Fcount=Fcount+1
1336    UNTIL Frequency>Stopf
1338    !
1340    Set_dbm(-140,0,@Sig_gen)
1342    ! GOSUB Save_data
1344    RETURN
1346    !
1348    ! ///////////////////////////////////////////////////////////////
1350    !
1352 Reduce_power:  !
1354    Dbm=Dbm-1
1356    Set_dbm(Dbm,1,@Sig_gen)
1358    IF Printflag THEN
1360        PRINTER IS Printer
1362        PRINT TIME$(TIMEDATE);":  Freq=";Frequency;
1364        PRINT RPT$("*",10);" NEW GENERATOR LEVEL =";Dbm
1366    END IF
1368    RETURN
1370    !
1372    ! ///////////////////////////////////////////////////////////////
1374    !
1376 Dual_pwr_error:  !
1378    Set_dbm(-140,0,@Sig_gen)
1380    IF Printflag THEN
1382        PRINTER IS Printer
1384        PRINT TIME$(TIMEDATE);":  Freq=";Frequency;
1386        PRINT RPT$("*",10);" ERROR IN DUAL POWER METER !!!"
1388    END IF
1390    STOP    !   Program dies here!
1392    RETURN
1394    !
1396    !///////////////////SERVICE DVM'S INTERUPT/////////////////////////
1398    !
1400 Check_dvm_done:  !
1402                  !Respond to an INTERUPT on the HPIB generated by one of
1404                  !two HP3456a DVMs.  Meaning that the data is ready.
1406                  !
1408    Ser_poll=SPOLL(@Dvm1)
1410    ENABLE INTR 7
1412    IF Ser_poll=66 THEN
1414        Read1_time=TIMEDATE-Trig1_time
1416        IF Bug1 THEN PRINT "DVM1 total sample time = ";Read1_time;" ";
1418        IF Bug1 THEN PRINT TIME$(TIMEDATE)
```

```
1420         !
1422         !.........................................................
1424         !Since the output of the detector is negative, Low and High are
1426         !swapped.
1428         Readdvm_stat(@Dvm1,High1,Low1,Mean1,Var1,Sam1) !Low and High swapped!
1430         !.........................................................
1432         !
1434         Low1=-1*Low1          !Crystal detector has negative output
1436         High1=-1*High1        !  "          "           "        "
1438         Mean1=-1*Mean1        !  "          "           "        "
1440         PRINT " DVM 1====",Low1,High1,Mean1,Var1,Sam1
1442         Read1flag=1
1444     END IF
1446     Ser_poll=SPOLL(@Dvm2)
1448     ENABLE INTR 7
1450     IF Ser_poll=66 THEN
1452         Read2_time=TIMEDATE-Trig2_time
1454         IF Bug1 THEN PRINT "DVM2 total sample time = ";Read2_time;" ";
1456         IF Bug1 THEN PRINT TIME$(TIMEDATE)
1458         Readdvm_stat(@Dvm2,Low2,High2,Mean2,Var2,Sam2)
1460         PRINT " DVM 2====",Low2,High2,Mean2,Var2,Sam2
1462         Read2flag=1
1464     END IF
1466     RETURN
1468     !
1470     !/////////////////****PROCESS DATA****/////////////////////////////
1472     !
1474 Process_data:  !
1476     !
1478     !Calculations for power read from spectrum analyzer.
1480     !
1482     Power=(.001)*10^(Power/10.)       !Convert dBm to watts.
1484     Cor_power=Power*C10_loss*C6a_loss*Pada_loss
1486     !.........................................................
1488     !ALSO EDIT PRINT STATEMENT IN LINE 1620
1490     !
1492     !Normalize to 10 mW/cm^2
1494     !
1496     Ref_pwr_den=(.4*PI*Frequency*Frequency*Cor_power)/9.0E+4
1498     Normal_pwr=SQR(10/Ref_pwr_den)
1500     !.........................................................
1502     !Normalize to 37 dB V/m
1504     !
1506     Ref_e_field=(4*PI*Frequency/300)*SQR(Cor_power*30)
1508     Normal_fld=(((10.0^(37/20))/Ref_e_field))
1510     !.........................................................
1512     !Calculations for CRYSTAL detector with 6 ft cable.
1514     !
1516     Cor_high1=(High1-Eut_zero)
1518     Cor_mean1=(Mean1-Eut_zero)
1520     IF Cor_high1<1.0E-50 THEN Cor_high1=1.0E-50
1522     IF Cor_mean1<1.0E-50 THEN Cor_mean1=1.0E-50
1524     !
1526     IF Cor_high1<=.1 THEN
1528         Cor_high1=.00304939*Cor_high1^(1.1195)!Convert to WATTS
1530     ELSE
1532         Cor_high1=.0135056*Cor_high1^(1.7488)!Convert to WATTS
1534     END IF
1536     !
1538     Cor_high1=Cor_high1*C10_loss
```

```
1540   Cor_high1=Cor_high1*Normal_pwr*Normal_pwr
1542   Cor_high1=10*LGT(Cor_high1/1.0E-3)              !Convert to dBm
1544   !
1546   IF Cor_mean1=.1 THEN
1548       Cor_mean1=.00304939*Cor_mean1^(1.1195)!Convert to WATTS
1550   ELSE
1552       Cor_mean1=.0135056*Cor_mean1^(1.7488)!Convert to WATTS
1554   END IF
1556   !
1558   Cor_mean1=Cor_mean1*C10_loss
1560   Cor_mean1=Cor_mean1*Normal_pwr*Normal_pwr
1562   Cor_mean1=10*LGT(Cor_mean1/1.0E-3)              !Convert to dBm
1564   !
1566   !Calculations for 1 cm DIPOLE with super amp.
1568   !
1570   Cor_high2=(High2-P1cm_zero)
1572   Return_field(Cor_high2,P1cm_fld_high)
1574   P1cm_fld_high=P1cm_fld_high*Normal_fld
1576   New_volts(P1cm_fld_high,Cor_high2)
1578   !
1580   Cor_mean2=(Mean2-P1cm_zero)
1582   Return_field(Cor_mean2,P1cm_fld_mean)
1584   P1cm_fld_mean=P1cm_fld_mean*Normal_fld
1586   New_volts(P1cm_fld_mean,Cor_mean2)
1588   !
1590   IF Cor_high2<1.0E-50 THEN Cor_high2=1.0E-50
1592   IF Cor_mean2<1.0E-50 THEN Cor_mean2=1.0E-50
1594   Cor_high2=20*LGT(Cor_high2*1000)        !dB mV
1596   Cor_mean2=20*LGT(Cor_mean2*1000)        !dB mV
1598   !
1600   Savedata(Fcount,1)=Frequency        !MHz
1602   Savedata(Fcount,2)=Netpower         !Watts
1604   Savedata(Fcount,3)=Ref_e_field      !V/m
1606   Savedata(Fcount,4)=Cor_high1        !dBm
1608   Savedata(Fcount,5)=Cor_mean1        !dBm
1610   Savedata(Fcount,6)=Cor_high2        !dB mV
1612   Savedata(Fcount,7)=Cor_mean2        !dB mV
1614   !
1616   RETURN
1618   !
1620   !////////////////////////****PRINT RAW DATA****//////////////////////
1622   !
1624 Print_alldata:!
1626   PRINTER IS Printer
1628   PRINT
1630   PRINT RPT$("-",80)
1632   PRINT "******************************";
1634   PRINT USING "2X,6D.DD,6A,2X,#";Frequency;" MHz "
1636   PRINT "******************************"
1638   PRINT RPT$("-",80)
1640   PRINT RPT$("_",80)
1642   PRINT "Measured RAW data:"
1644   PRINT
1646   PRINT "         PWR IN            MAX REC PWR     HORN ZERO    HORN PEAK";
1648   PRINT "   HORN MEAN"
1650   PRINT "    INC--Watts--REF          Watts             mV            mV    ";
1652   PRINT "        mV"
1654 Spyraw1:IMAGE MD.4DE,X,MD.4DE,XX,MD.4DE,XX,6D.2D,3X,#
1656 Spyraw2:IMAGE 7D.2D,X,7D.2D
1658   PRINT USING Spyraw1;Incpwr_raw,Refpwr_raw,Power,Eut_zero*1000
```

```
1660   PRINT USING Spyraw2;High1*1000,Mean1*1000
1662   !
1664   PRINT
1666   PRINT "1cm PRB ZERO     1cm PRB PEAK     1cm PRB MEAN     Signal Gen Level"
1668   PRINT "      mV                mV                mV                 dBm"
1670 Spyraw3:IMAGE 6D.2D,6X,7D.2D,6X,7D.2D,10X,5D
1672   PRINT USING Spyraw3;P1cm_zero*1000,High2*1000,Mean2*1000,Dbm
1674   PRINT
1676   PRINT RPT$("_",80)
1678   PRINT "PROCESSED DATA:"
1680   PRINT "HORN  normalized to 10 mW/cm^2, 1cm DIPOLE normalized to 37";
1682   PRINT " dB V/m."
1684   PRINT
1686   PRINT "REC PWR CORR.   HORN PEAK   HORN MEAN   ";
1688   PRINT "1cm PRB PK   1cm PRB MEAN"
1690   PRINT "   Watts             dBm          dBm       ";
1692   PRINT "  dB mV           dB mV"
1694 Spyraw6:IMAGE MD.4DE,5X,M4D.2D,3X,#
1696 Spyraw7:IMAGE M6D.2D,2X,M4D.2D,4X,M4D.2D
1698   !
1700   PRINT USING Spyraw6;Cor_power,Cor_high1
1702   PRINT USING Spyraw7;Cor_mean1,Cor_high2,Cor_mean2
1704   PRINT TAB(41);RPT$("_",25)
1706   PRINT TAB(41);"Field V/m    Field V/m"
1708   PRINT USING "39X,M4D.2D,4X,M4D.2D";P1cm_fld_high,P1cm_fld_mean
1710   PRINT
1712   PRINT RPT$("-",65)
1714   PRINT "REC PWR CORR.    NET INPUT POWER   REF PWR DENSITY  REF FIELD"
1716   PRINT "    dBm                 Watts              mW/cm^2         V/m"
1718 Spyraw8:IMAGE X,M4D.2D,10X,MD.4DE,6X,M2D.4D,5X,M4D.4D
1720   Power_dbm=10*LGT(1000*Cor_power)
1722   PRINT USING Spyraw8;Power_dbm,Netpower,Ref_pwr_den,Ref_e_field
1724   PRINT RPT$("_",80)
1726   PRINT RPT$("*",80)
1728   PRINT RPT$("_",80)
1730   PRINT
1732   PRINTER IS CRT
1734   RETURN
1736   !
1738   !///////////////////////****SAVE DATA****/////////////////////////
1740   !
1742 Save_data:  !
1744   RETURN
1746   DISP "ENTER FILE NAME FOR THIS DATA (<=10 CHRS/NUMS ONLY) ";
1748   BEEP
1750   LINPUT Filename$
1752   IF LEN(Filename$)>10 THEN Save_data
1754   Filename$=Filename$&Outdisk$
1756   ON ERROR CALL Errortrap
1758   CREATE BDAT Filename$,(7*Totalfreqs+128),8
1760   ASSIGN @Datapath TO Filename$
1762   OUTPUT @Datapath;Totalcurves
1764   OUTPUT @Datapath;Totalfreqs
1766   OUTPUT @Datapath;Totalfreqs
1768   OUTPUT @Datapath;Savedata(*)
1770   ASSIGN @Datapath TO *
1772   !
1774   PRINTER IS Printer
1776   PRINT TIME$(TIMEDATE);"............DATA STORED ON FILE ";
1778   PRINT Filename$[1,POS(Filename$,":")-1];".............."
```

```
1780    PRINTER IS 1
1782    OFF ERROR
1784    RETURN
1786    !
1788    END
1790    !
1792    !******************************************************************
1794    !
1796    SUB Measure_menu
1798                              !
1800                              !This routine will facilitate setting up the
1802                              !measurement.
1804                              !
1806        COM /Parameters/ Startf,Stopf,Stepf,Slow_down,Coupler_id$[10]
1808        COM /Parameters/ Generator_id$[10],Dvm_integrat$[3]
1810        COM /Parameters/ INTEGER Low_dbm,High_dbm,Step_dbm,Dvm_samples
1812        COM /Parameters/ Upperlimit,Threshold,Rev_time
1814        COM /Motor_menu/ Motion_type$[10],INTEGER Jog_wait
1816        COM /Bugs/ INTEGER Bug1,Bug2,Bug3,Printer
1818        !
1820        DIM Eut_identity$[160],Operator_name$[60]
1822        !
1824        PRINTER IS 1
1826        Wipe_clean            !Clear the CRT.
1828        !
1830        !Define the choices at start-up.
1832        !
1834        Operator_name$="Mike Crawford"
1836        !
1838        Startf=2000           !Frequency range in MHz.
1840        Stopf=4000
1842        Stepf=200
1844        !
1846        Low_dbm=-30                !Signal generator level in dBm.
1848        High_dbm=-10
1850        Step_dbm=1
1852        !
1854        Eut_identity$="Evaluate use of NSWC Reverberating Chamber "
1856        Eut_identity$=Eut_identity$&"for measuring response of EUT."
1858        !
1860        Threshold=50.0        !EUT LOWER THRESHOLD VOLTAGE. mV.
1862        Upperlimit=1200.0      !EUT FAILURE VOLTAGE. mV.
1864        !
1866        Slow_down=.02         !Time for EUT to respond after field is set.
1868        !
1870        Jog_wait=10           !Wait .10 seconds between each of 3200 jogs.
1872        !
1874        Coupler_id$="HP_11692D"
1876        Generator_id$="HP_8672A"
1878        !
1880        !Display the above parameters.
1882        !
1884        PRINT CHR$(129)
1886        PRINT TABXY(16,1);" MEASUREMENT PARAMETERS FOR MODE STIRRED TESTS. "
1888        PRINT TABXY(1,3);"  TEST DESCRIPTION: "
1890        PRINT TABXY(1,7);"  FREQUENCY RANGE  "
1892        PRINT TABXY(30,7);"TO"
1894        PRINT TABXY(42,7);"STEP"
1896        PRINT TABXY(56,7);"MHz."
1898        PRINT TABXY(1,9);"  SIG-GEN RANGE "
```

```
1900        PRINT TABXY(22,9);"TO"
1902        PRINT TABXY(29,9);" / "
1904        PRINT TABXY(37,9);"dBm."
1906        PRINT TABXY(44,9);" EUT RESPONSE TIME "
1908        PRINT TABXY(70,9);" Sec. "
1910        PRINT TABXY(45,11);" FAIL LIMIT mV "
1912        PRINT TABXY(1,11);"  EUT LOWER THRESHOLD RESPONSE mV "
1914        PRINT TABXY(1,13);" EST. TIME/Tuner rev "
1916        PRINT TABXY(33,13);" DVM SAMPLES "
1918        PRINT TABXY(53,13);" LINE CYCLES/SAMPLE "
1920        PRINT TABXY(40,15);" COUPLER/SIG GEN "
1922        PRINT TABXY(1,15);"  DATE/TIME "
1924        PRINT TABXY(1,17);"  OPERATOR'S NAME "
1926        PRINT CHR$(128)
1928        !
1930        !Fill in the default choices.
1932        !
1934        GOSUB Print_eutid
1936        GOSUB Print_freqs
1938        GOSUB Print_gen_level
1940        GOSUB Print_eutfail
1942        GOSUB Print_slowdown
1944        GOSUB Print_thresh
1946        GOSUB Print_tuner
1948        GOSUB Print_name
1950        !
1952        !Make any changes or corrections.
1954        !
1956        OFF KEY
1958        ON KEY 0 LABEL "TEST ID",5 GOSUB Change_eutid
1960        ON KEY 1 LABEL "Frequency",5 GOSUB Change_freqs
1962        ON KEY 2 LABEL "GEN Levels ",5 GOSUB Change_levels
1964        ON KEY 3 LABEL "THRESHOLD",5 GOSUB Change_thresh
1966        ON KEY 4 LABEL "FAIL LIMIT",5 GOSUB Change_eutfail
1968        ON KEY 8 LABEL "TUNER REVs",5 GOSUB Change_tuner
1970        ON KEY 5 LABEL "CONTINUE",5 GOSUB Exit_sub
1972        ON KEY 6 LABEL "YOUR NAME",5 GOSUB Enter_name
1974        ON KEY 7 LABEL "RESPONSE tm",5 GOSUB Change_respond
1976        ON KEY 8 LABEL "TUNER REVs",5 GOSUB Change_tuner
1978        ON KEY 5 LABEL "CONTINUE",5 GOSUB Exit_sub
1980        ON KEY 9 LABEL " DATE ",5 CALL Time_date
1982        BEEP
1984        PRINT TABXY(14,15);DATE$(TIMEDATE)
1986 Spin:       !
1988        DISP "<<<<<<<<<<< SELECT PARAMETER TO CHANGE >>>>>>>>>>>"
1990        PRINT TABXY(28,15);TIME$(TIMEDATE)
1992        GOTO Spin
1994 Exit_sub:       !
1996        Upperlimit=Upperlimit/1000!Convert to volts
1998        Threshold=Threshold/1000!Convert to volts
2000        OFF KEY
2002        DISP CHR$(12)
2004        PRINTER IS Printer
2006        IF Printer=701 THEN DUMP ALPHA
2008        CALL Wipe_clean
2010        SUBEXIT
2012        !
2014        !////////////////////////////////////////////////////////////
2016        !
2018 Change_tuner:   !
```

```
2020       Jog_wait=Jog_wait+1
2022 Print_tuner:   !
2024       Rev_time=38.37068*Jog_wait+4.92406
2026       !
2028       Dvm_samples=INT(1.15*(38.9729+23.60383*(Rev_time)))  ! .1 cycle
2030       Dvm_integrat$=".1"
2032       !
2034       IF Dvm_samples>9999 THEN
2036           Dvm_samples=INT(1.15*(3.970658+12.8621757*(Rev_time)))! 1 cycle
2038           Dvm_integrat$="1"
2040       END IF
2042       IF Dvm_samples>9999 THEN
2044           Jog_wait=0
2046           GOTO Change_tuner
2048       END IF
2050       Hh=Rev_time DIV 3600
2052       Mm=(Rev_time-Hh*3600) DIV 60
2054       Ss=INT(Rev_time-Hh*3600) MOD 60
2056       PRINT TABXY(23,13);
2058       PRINT USING "DD,A,ZZ,A,ZZ";Hh,":",Mm,":",Ss
2060       PRINT TABXY(47,13);Dvm_samples
2062       PRINT TABXY(74,13);"    "
2064       PRINT TABXY(74,13);Dvm_integrat$
2066       RETURN
2068       !
2070       !//////////////////////////////////////////////////////////////////////
2072       !
2074 Change_eutid:  !
2076       DISP "DESCRIPTION of the EUT and PURPOSE for test?? (<2 lines)";
2078       OUTPUT 2 USING "K,#";Eut_identity$
2080       LINPUT Eut_identity$
2082 Print_eutid:  !
2084       PRINT TABXY(1,4);RPT$(" ",160)
2086       PRINT TABXY(1,4);Eut_identity$
2088       RETURN
2090       !
2092       !/////////////////////////////////////////////////////////////////
2094       !
2096 Change_freqs:  !
2098       DISP "ENTER the START, STOP, and STEP frequencies (MHz) ";
2100       INPUT Startf,Stopf,Stepf
2102       IF Startf<100 THEN Startf=100
2104       IF Startf>18000 THEN Startf=18000
2106       SELECT Startf
2108       CASE <2000
2110           IF Stopf>2000 THEN Stopf=2000
2112           Coupler_id$="HP_778D"
2114           Generator_id$="HP_8660A"
2116       CASE >=2000
2118           IF Stopf>18000 THEN Stopf=18000
2120           Coupler_id$="HP_11692D"
2122           Generator_id$="HP_8672A"
2124       END SELECT
2126 Print_freqs: !
2128       PRINT TABXY(21,7);
2130       PRINT USING "5D.2D";Startf
2132       PRINT TABXY(33,7);
2134       PRINT USING "5D.2D";Stopf
2136       PRINT TABXY(47,7);
2138       PRINT USING "5D.2D";Stepf
```

```
2140        PRINT TABXY(58,15);RPT$(" ",10)
2142        PRINT TABXY(69,15);RPT$(" ",10)
2144        PRINT TABXY(58,15);Coupler_id$
2146        PRINT TABXY(69,15):Generator_id$
2148        RETURN
2150        !
2152        !//////////////////////////////////////////////////////////////
2154        !
2156 Change_levels:  !
2158     ! DISP "ENTER Signal generator LEVEL (dBm) ";
2160     ! INPUT Dbm
2162     ! Low_dbm=INT(Dbm)
2164        DISP "LOW, HIGH, STEP Signal generator LEVEL (dBm) ";
2166        INPUT Low_dbm,High_dbm,Step_dbm
2168 Print_gen_level:  !
2170        PRINT TABXY(17,9);
2172        PRINT USING "4D";Low_dbm
2174        PRINT TABXY(24,9);
2176        PRINT USING "4D";High_dbm
2178        PRINT TABXY(32,9);
2180        PRINT USING "4D";Step_dbm
2182        RETURN
2184        !
2186        !///////////////////////////////////////////////////////////////
2188        !
2190 Change_eutfail:  !
2192        DISP "ENTER the UPPER LIMIT for the EUT RESPONSE (mV)";
2194        INPUT Upperlimit
2196 Print_eutfail:   !
2198        PRINT TABXY(60,11);Upperlimit
2200        RETURN
2202        !
2204        !//////////////////////////////////////////////////////////////////
2206        !
2208 Change_thresh:  !
2210        DISP "LOWER LIMIT EUT RESPONSE for initially setting field. (mV) ";
2212        INPUT Threshold
2214 Print_thresh:   !
2216        PRINT TABXY(35,11);Threshold
2218        RETURN
2220        !
2222        !///////////////////////////////////////////////////////////////
2224        !
2226 Change_respond:    !
2228        DISP "WAIT TIME FOR EUT TO RESPOND AFTER FIELD IS SET.";
2230        INPUT Slow_down
2232 Print_slowdown:   !
2234        PRINT TABXY(64,9);RPT$(" ",6)
2236        PRINT TABXY(64,9);Slow_down
2238        RETURN
2240        !
2242        !/////////////////////////////////////////////////////////
2244        !
2246 Enter_name:  !
2248        DISP "PLEASE TYPE IN YOUR NAME ";
2250        LINPUT Operator_name$
2252 Print_name:  !
2254        PRINT TABXY(20,17);Clear_opname$
2256        PRINT TABXY(20,17);Operator_name$
2258        RETURN
2260        !
2262        ! ////////////////////////////////////////////////////////////////
2264        !
2266   SUBEND
2268   !
2270   ! ***************************************************************
2272   !
```

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report presents the results of work at the National Bureau of Standards, Boulder, Colorado, to carefully evaluate, document, develop (when necessary), and describe the methodology for performing radiated susceptibility/vulnerability measurements using a reverberation chamber. The report describes the reverberation chamber theory of operation, construction, evaluation, functional operation, and use for performing immunity measurements. It includes an estimate of measurement uncertainties derived empirically from test results and from comparisons with anechoic chamber measurements. Finally, it discusses the limitations and advantages of the measurement technique to assist potential users in determining the applicability for this technique to their electromagnetic compatibility (EMC) measurement needs.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

electromagnetic susceptibility/vulnerability; estimated uncertainty; evaluation; measurement procedures; reverberabtion chamber

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